NOTICE!

ALL DRAWINGS
ARE LOCATED
AT THE END OF
THE DOCUMENT

TECHNICAL MEMORANDUM NO. 1

HUMAN HEALTH RISK ASSESSMENT

PRESENT LANDFILL (IHSS 114), THE INACTIVE HAZARDOUS WASTE STORAGE AREA (IHSS 203), AND THE EAST LANDFILL POND AND ADJACENT SPRAY EVAPORATION AREAS OPERABLE UNIT NO. 7

EXPOSURE SCENARIOS

DRAFT FINAL
JANUARY 15, 1993

ROCKY FLATS PLANT

U.S. DEPARTMENT OF ENERGY
ROCKY FLATS PLANT
GOLDEN, COLORADO

ENVIRONMENTAL MANAGEMENT DEPARTMENT

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

This technical memorandum supports the Baseline Risk Assessment (BRA) for the Phase I Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI)/Remedial Investigation (RI) for Operable Unit No. 7 (OU7) at the Rocky Flats Plant (RFP). OU7 consists of the following individual hazardous substance sites (IHSSs):

- Present Landfill (IHSS 114)
- Inactive Hazardous Waste Storage Area (IHSS 203)

Also included within the boundary of OU7 are the East Landfill Pond and adjacent spray evaporation areas. Leachate and groundwater from the IHSSs drain into the East Landfill Pond, with water from the East Landfill Pond sprayed along its banks to facilitate evaporation of pond water.

RFP is a government-owned and contractor-operated (GOCO) facility that is part of the nationwide nuclear weapons production complex. Its historical mission was to produce metal components for nuclear weapons. These components were fabricated from plutonium, uranium, and nonradioactive metals (principally beryllium and stainless steel) and shipped elsewhere for final assembly. RFP is currently performing environmental restoration activities and transition planning for decontamination and decommissioning. The facility is located on approximately 6,550 acres of federally owned land in northern Jefferson County, Colorado, approximately 16 miles northwest of Denver. Surrounding communities include Boulder, Superior, Broomfield, Westminster, and Arvada, which are located less than 10 miles to the northwest, north, northeast, and southeast, respectively.

This memorandum presents the exposure assessment approach for the Human Health Risk Assessment (HHRA) portion of the BRA for OU7. The HHRA will evaluate human health risks for onsite and offsite receptors under current and future land use conditions.

The RFI/RI is performed pursuant to an Interagency Agreement (IAG) among the U.S. Department of Energy (DOE), the U.S. Environmental Protection Agency (EPA), and the Colorado Department of Health (CDH) dated January 22, 1991 (DOE 1991a). As required by the IAG, a Phase I RFI/RI will characterize source materials and soils at OU7. Through subsequent discussions with CDH, it has been directed that the HHRA for the Phase I RFI/RI for OU7 include air pathway analyses. A subsequent Phase II RFI/RI will investigate the nature and extent of surface water, leachate, biota and groundwater contamination and evaluate potential contamination migration pathways.

The scope of this technical memorandum is limited to the identification of:

- Exposure pathways and associated intake routes and parameters for Phase I RFI/RI characterized source materials and soil within OU7

- Current and future human exposure scenarios for characterized source materials and soil within OU7

Because the nature and extent of surface water, leachate, biota and groundwater contamination will not be investigated until the Phase II RFI/RI process, this technical memorandum addresses only direct (e.g., contact) and upward (e.g., wind suspension) exposure pathways associated with Phase I RFI/RI characterized source materials and soil. These source and soil materials will be used as input to environmental transport models in order to assess risks to human health. Subsequent technical memoranda and human risk analyses will be prepared as part of the Phase II RFI/RI process for OU7.

The objectives of this technical memorandum were to identify (1) complete exposure pathways by which chemicals may be transported from Phase I RFI/RFI identified sources to human exposure points, (2) associated human receptor populations that may be exposed to the identified chemicals, (3) the route(s) of chemical intake, and (4) intake parameters for each contaminated medium (e.g., soil). Chemical intakes have not been quantified. The magnitude of exposure is dependent on the chemical concentration at the exposure points, which will be estimated based on the analytical results of the Phase I RFI/RI and fate and transport modeling, as appropriate. The exposure assessment focuses on media (e.g., soil) that potentially contain chemicals related to Phase I RFI/RI identified sources and associated exposure pathways, potential receptors, exposure points, and factors for potential human intake of impacted media.

A conceptual site model (CSM) of potential human exposure pathways was developed to provide a schematic representation of the chemical source areas, chemical release mechanisms, environmental transport media, potential human intake and exposure routes, and potential human receptors. The purpose of the CSM is to provide a framework for problem definition, identify exposure pathways that may result in human health risks, indicate data gaps, and aid in identifying appropriate remediation measures. Chemical release mechanisms, environmental transport media, and potential human intake and exposure routes to the contaminated site soil were identified for each potential receptor.

Current offsite residents, hypothetical future onsite workers, and hypothetical future onsite ecological researchers are included among the receptor scenarios to be quantitatively evaluated on the basis of their credibility and representative or bounding exposure potential. While a future hypothetical onsite resident has been shown to be improbable, this exposure scenario has been retained for quantitative evaluation so that the full range of risks can be examined by the regulatory agencies. Two exposure points were selected for the current offsite resident on the basis of proximity to the plant site and the predominant wind direction. The hypothetical future onsite resident, worker, and ecological researcher are all located within the boundaries of OU7. While the hypothetical future onsite worker is a credible exposure scenario, this receptor category is more likely to have an exposure location within the existing developed area of the plant site because of its existing infrastructure of facilities and utilities. Complete human health exposure pathways to be evaluated as part of the HHRA for OU7 are:

Current Offsite Resident

- Inhalation of airborne particulates
- Inhalation of outdoor VOCs
- Soil ingestion following airborne deposition of particulates on residential soil
- Dermal contact with soil, following airborne deposition of particulates
- Ingestion of vegetables following surface deposition of particulates

Hypothetical Future Onsite Worker

- Inhalation of VOCs in indoor and outdoor air
- Inhalation of airborne particulates
- Incidental soil ingestion
- Direct dermal contact with soil
- Groundshine (external radiation) (direct contact)

Hypothetical Future Onsite Ecological Worker

- Inhalation of outdoor VOCs and airborne particulates
- Incidental soil ingestion
- Direct dermal contact with soil
- Groundshine (direct contact)

Hypothetical Future Onsite Resident

- Inhalation of VOCs in indoor and outdoor air
- Inhalation of airborne particulates
- Ingestion of homegrown vegetables (surface deposition of particulates and root uptake of site-related chemicals)
- Incidental soil ingestion
- Direct dermal contact with soil
- Groundshine (direct contact)

Intakes and exposures were estimated using reasonable estimates of body weight, inhalation volume, ingestion rates, soil or food matrix effects, and frequency and duration of exposure. Intakes and exposures will be estimated for reasonable maximum exposure (RME) conditions. The RME was estimated by selecting values for exposure that can reasonably be expected to occur at the site. The intake and exposure parameters to be used in the HHRA for each of the exposure scenarios indicated above are presented in Section 5.0 of this technical memorandum.

1.0 INTRODUCTION

This technical memorandum supports the BRA for the Phase I RFI/RI for OU7. OU7 consists of the following IHSSs:

- Present Landfill (IHSS 114)
- Inactive Hazardous Waste Storage Area (IHSS 203)

Also included within the boundary of OU7 are the East Landfill Pond and adjacent spray evaporation areas. Leachate and groundwater from the IHSSs drain into the East Landfill Pond, with water from the East Landfill Pond sprayed along its banks to facilitate evaporation of pond water.

The BRA is comprised of a HHRA and an environmental evaluation. This memorandum presents the exposure assessment approach for the HHRA portion of the BRA for OU7. The HHRA will evaluate human health risks for onsite and offsite receptors under current and future land use conditions.

The RFI/RI is performed pursuant to the IAG among DOE, EPA, and CDH dated January 22, 1991 (DOE 1991a). As required by the IAG, a Phase I RFI/RI will characterize source materials and soils at OU7. Through subsequent discussions with CDH, it has been directed that the HHRA for the Phase I RFI/RI for OU7 include air pathway analyses. A subsequent Phase II RFI/RI will investigate the nature and extent of surface water, leachate, biota and groundwater contamination and evaluate potential contamination migration pathways.

1.1 Objectives

The objectives of this technical memorandum are to identify (1) complete exposure pathways by which chemicals may be transported from Phase I RFI/RFI identified sources to human exposure points, (2) associated human receptor populations that may be exposed to the identified chemicals, (3) the route(s) of chemical intake, and (4) intake parameters for each contaminated medium (e.g., soil). Chemical intakes have not been quantified. The magnitude of exposure is dependent on the chemical concentration at the exposure points, which will be estimated based on the analytical results of the Phase I RFI/RI and fate and transport modeling, as appropriate. The exposure assessment focuses on media (e.g., soil) that potentially contain chemicals related to Phase I RFI/RI identified sources and associated exposure pathways, potential receptors, exposure points, and factors for potential human intake of impacted media.

1.2 Scope

The scope of this technical memorandum is limited to the identification of:

- Exposure pathways and associated intake routes and parameters for Phase I RFI/RI characterized source materials and soil within OU7

- Current and future human exposure scenarios for characterized source materials and soil within OU7

Because the nature and extent of surface water, leachate, biota and groundwater contamination will not be investigated until the Phase II RFI/RI process, this technical memorandum addresses only direct (e.g., contact) and upward (e.g., wind suspension) exposure pathways associated with Phase I RFI/RI characterized source materials and soil. Subsequent technical memoranda and human risk analyses will be prepared as part of the Phase II RFI/RI process for OU7.

Potential scenarios were identified according to the EPA concept of reasonable maximum exposure (RME), defined as the highest exposure reasonably expected to occur at a site (EPA 1989b). The term "potential" is used to mean "a reasonable chance of occurrence within the context of the reasonable maximum exposure scenario" (EPA 1990). Using this approach, potential exposures are evaluated in Section 4.0 using a conceptual site model. In the CSM, the likelihood of an exposure pathway occurring is classified as significant, insignificant, or negligible (i.e., incomplete). In this document, negligible or incomplete pathways are those that are unlikely to occur, significant pathways are those that could conceivably occur, and insignificant pathways are those that could also occur but are expected to result in relatively lower levels of exposure (i.e., by one or more orders of magnitude) with respect to significant exposure pathways.

This technical memorandum is organized as follows: Section 2.0, Site Description, describes site characteristics that potentially impact human exposures. These characteristics include site history, meteorology, geology, and surface and groundwater hydrology. Section 3.0, Potentially Exposed Receptor Populations, identifies the populations that may be exposed to chemicals originating from identified site-related sources. Land uses and exposure scenarios that are most likely to occur, given the site-specific conditions, are identified for quantitative assessment in the HHRA. Section 4.0, Exposure Pathways, discusses the potential release and transport of chemicals from the site, and identifies exposure pathways to be evaluated in the HHRA using a conceptual site model. Section 5.0, Estimating Chemical Intakes, describes the methodology used to approximate the intake of chemicals in various media and identifies chemical intake factors for the calculation of chemical intake by human receptors. Section 6.0 lists the references cited throughout this document.

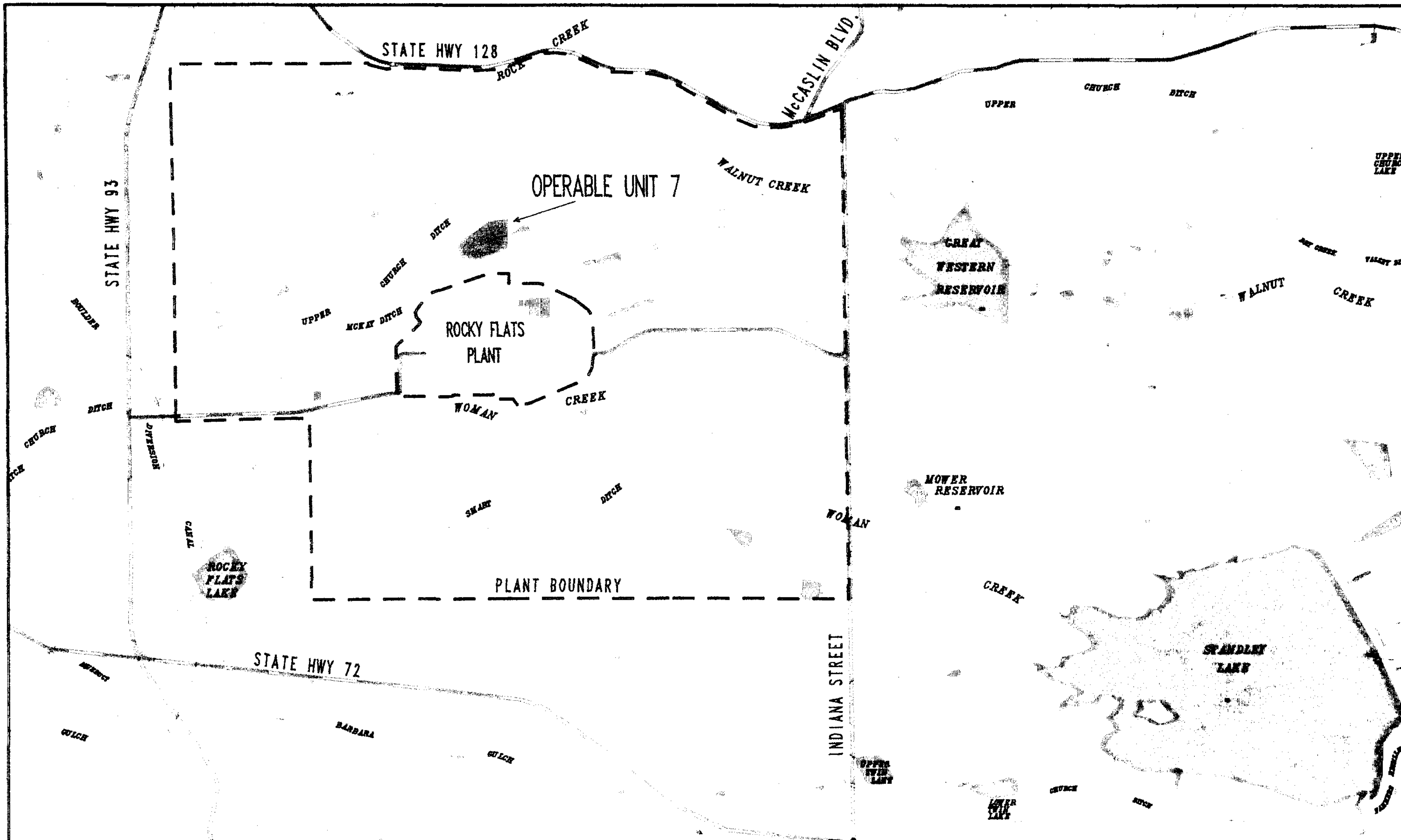
2.0 SITE DESCRIPTION

2.1 Location and Plant History

RFP is located on approximately 6,550 acres of federally owned land in northern Jefferson County, Colorado, approximately 16 miles northwest of Denver (Figure 2-1). Surrounding communities include Boulder, Superior, Broomfield, Westminster, and Arvada, which are located less than 10 miles to the northwest, north, northeast, and southeast, respectively. RFP includes an industrial complex of approximately 400 acres known as the protected area (PA), surrounded by a buffer zone of approximately 6,150 acres. A general description of RFP is presented in this section. For a more detailed description, please refer to the Phase I RFI/RI Work Plan for OU7 (DOE 1991b).

RFP is a government-owned and contractor-operated (GOCO) facility that is part of the nationwide nuclear weapons production complex. RFP was operated for the U.S. Atomic Energy Commission (AEC) from the time it was built in 1951 until the AEC was dissolved in January 1975. At that time, responsibility for RFP was assigned to the Energy Research and Development Administration (ERDA), which was succeeded by the Department of Energy (DOE) in 1977. Dow Chemical USA, an operating unit of the Dow Chemical Company, was the prime operating contractor of the facility from 1951 until June 30, 1975, when it was succeeded by Rockwell International. EG&G Rocky Flats, Inc. succeeded Rockwell International on January 1, 1990.

RFP's historical mission was to produce metal components for nuclear weapons. These components were fabricated from plutonium, uranium, and nonradioactive metals (principally beryllium and stainless steel) and shipped elsewhere for final assembly. When a nuclear weapon is determined to be obsolete, components of these weapons fabricated at RFP are returned for special processing to recover plutonium. Other activities at RFP have included research and development in metallurgy, machining, nondestructive testing, coatings, remote engineering, chemistry, and physics. Both radioactive and nonradioactive wastes have been generated in these research and production processes. Current waste handling practices involve onsite and offsite recycling of hazardous materials, onsite storage



Approx. Scale 1" = 4000'

0 feet 4000 8000

LOCATION of the ROCKY FLATS PLANT and OPERABLE UNIT 7

N

FIGURE 2-1

of hazardous and radioactive mixed wastes, and disposal of solid radioactive materials at another DOE facility. Historically, the operating procedures included both onsite storage and disposal of hazardous and radioactive wastes. Preliminary assessments under the ER Program identified some of the past onsite storage and disposal locations as potential sources of environmental contamination.

RFP is currently performing environmental restoration activities and transition planning for decontamination and decommissioning. In a recent speech given at RFP, the Secretary of Energy, James Watkins, outlined DOE's plans for the future use of RFP. Watkins characterized RFP as an attractive site for manufacturers and other businesses (Denver Post 1992).

A group of local business and government representatives, referred to as the Rocky Flats Local Impacts Initiative (RFLII), has been formed to identify and mitigate negative economic impacts associated with the transition currently occurring at the RFP. One of the goals of RFLII's is to work with DOE and local economic development agencies to identify and attract businesses to occupy existing buildings at the site (RFLII 1992). To this end, RFLII recently drafted criteria to be applied in targeting businesses for future occupation of the RFP (see Section 3.0).

Another relatively recent development at RFP has been the realization of its value as wildlife habitat and a refuge for regionally limited plant and animal species. The ecological importance of the site has resulted from various geographic influences and the fact that the buffer zone has been protected from grazing and most other physical disturbances for decades. The ecology of the site is described more fully in Section 2.4; its impact on future land use and exposure scenarios is discussed in Section 3.0.

2.2 History of OU7

OU7 comprises the Present Landfill (IHSS 114), the East Landfill Pond and adjacent spray evaporation areas, and the Inactive Hazardous Waste Storage Area (IHSS 203). Figure 2-2 illustrates the locations of these areas and the OU7 boundary. The following IHSS descriptions are based on the Phase I RFI/RI Work Plan for OU7.

2.2.1 Present Landfill (IHSS 114)

Operation of the landfill was initiated on August 14, 1968. A portion of the natural drainage was filled with soils from an onsite borrow area to a depth of up to 5 feet to construct a surface on which to start landfilling. The landfill was originally constructed to provide for disposal of the plant's nonradioactive solid wastes. Waste materials disposed in the landfill have included paper, rags, floor sweepings, cartons, mixed garbage and rubbish, demolition material, and miscellaneous items.

From 1968 to 1978, the landfill received approximately 20 cubic yards of compacted waste per day. By 1974, the landfill had expanded in surface area to approximately 300,000 square feet (7 acres). The volume occupied by the landfill was estimated to be approximately 95,000 cubic yards. Of this total, the cover material was estimated at 30,000 cubic yards. The remaining 65,000 cubic yards consisted of compacted waste intermixed with the daily cover material placed during disposal. Estimates made in 1986 indicate that approximately 160,000 cubic yards of material had been placed between 1974 and 1986, for a total landfill volume of 255,000 cubic yards. This volume included solid wastes, wastes with hazardous constituents, and soil cover material. Between 1986 and 1988, waste was disposed at a rate of 115 cubic yards per work day (Rockwell 1988a). Using this rate and assuming 260 work days per year for four years, approximately 120,000 cubic yards of waste material have been disposed since 1986. Daily cover volumes have been estimated at approximately 25 percent of the volume of material disposed. Based on these assumptions, the present volume of material in the landfill is estimated to be approximately 405,000 cubic yards.

In September 1973, tritium was detected in leachate draining from the landfill. Subsequently, a sampling program was initiated to determine the location of the tritium source monitoring of waste prior to burial was initiated to prevent further disposal of radioactive material, and interim response measures were undertaken to control the generation and migration of the landfill leachate.

The disposal procedures currently employed at the landfill have not changed significantly since the landfill went into operation in 1968. Waste is delivered to the landfill throughout the morning and early afternoon. In mid-afternoon, waste is spread across the work area.

Since the discovery in 1973 of a tritium source within the landfill wastes, a radiation monitoring program initiated by the Health Physics Operations at RFP has been implemented to prevent further disposal of radioactive material. After the waste is dumped, but before compaction and burial, measurements are obtained with a Field Instrument for Detection of Low Energy Radiation (FIDLER) probe. Radioactive items are removed and stored onsite.

After radiation monitoring is completed, the waste layer is compacted and covered with 6 inches of soil from onsite stockpiles. Waste disposal continues in this manner until the waste layer is within 3 feet of the final elevation. The lift is then completed by adding a layer of compacted soil 3 feet thick. In different sections of the landfill, the total landfill thickness consists of one to three such lifts. Based on visual observation (Rockwell 1988a), some areas of the landfill surface may not have received a full 3-feet of compacted soil.

2.2.2 East Landfill Pond and Adjacent Spray Evaporation Areas

Interim measures taken in response to the detection of tritium in the landfill leachate included construction of two ponds (Ponds #1 and #2) immediately east of the landfill, a subsurface interception system for diverting groundwater around the landfill, a subsurface leachate collection system, and surface water control ditches. Construction of these systems began in October 1974 and was completed in January 1975. The locations of the landfill structures constructed as interim response measures are shown in Figure 2-3.

The surface water control ditches intercept surface water runoff flowing toward the landfill and direct it away from the landfill. The purpose of Pond #1 (the West Landfill Pond) was to provide a permanent structure to impound any leachate generated by the landfill. The purpose of Pond #2 (the East Landfill Pond) was to provide a permanent structure to collect groundwater flowing from the groundwater diversion system. The leachate collection system drained only to the West Landfill Pond. Discharge of the intercepted groundwater could be directed to the west pond, east pond, or surface drainages downgradient of the east pond by a series of valves in the subsurface pipes.

In 1974, an engineered pond embankment was constructed to replace the temporary embankment of Pond #2. The engineered embankment included a low-permeability clay core keyed into bedrock. The area of the new pond, now called the East Landfill Pond, was approximately 2.5 acres.

To prevent the two ponds from overfilling and discharging into the drainage, water was periodically sprayed in areas adjacent to the landfill to enhance evaporation. Areas where spray operations historically occurred were designated as IHSSs and incorporated into OU6. Water collected in Pond #1 was sprayed on a 3.9-acre plot, designated as IHSS 167.1 and located approximately 800 feet northeast of the pond. Two other spray fields, IHSSs 167.2 and 167.3, were located along the banks of Pond #2 and were used for spray evaporation of water collected from that pond. Water from Pond #2 (the East Landfill Pond) is currently sprayed along the banks on south side of the pond in areas not designated as IHSSs but considered to be part of OU7.

Between 1977 and 1981, portions of the leachate and groundwater diversion system were buried during landfill expansion. The eastward expansion covered the discharge points of the leachate collection system into Pond #1. The west embankment and Pond #1 were covered in May 1981 during further eastward expansion of the landfill. In 1982, two slurry walls were constructed to prevent groundwater migration into the expanded landfill area. These slurry walls were tied into the north and south arms of the groundwater diversion system.

2.2.3 Inactive Hazardous Waste Storage Area (IHSS 203)

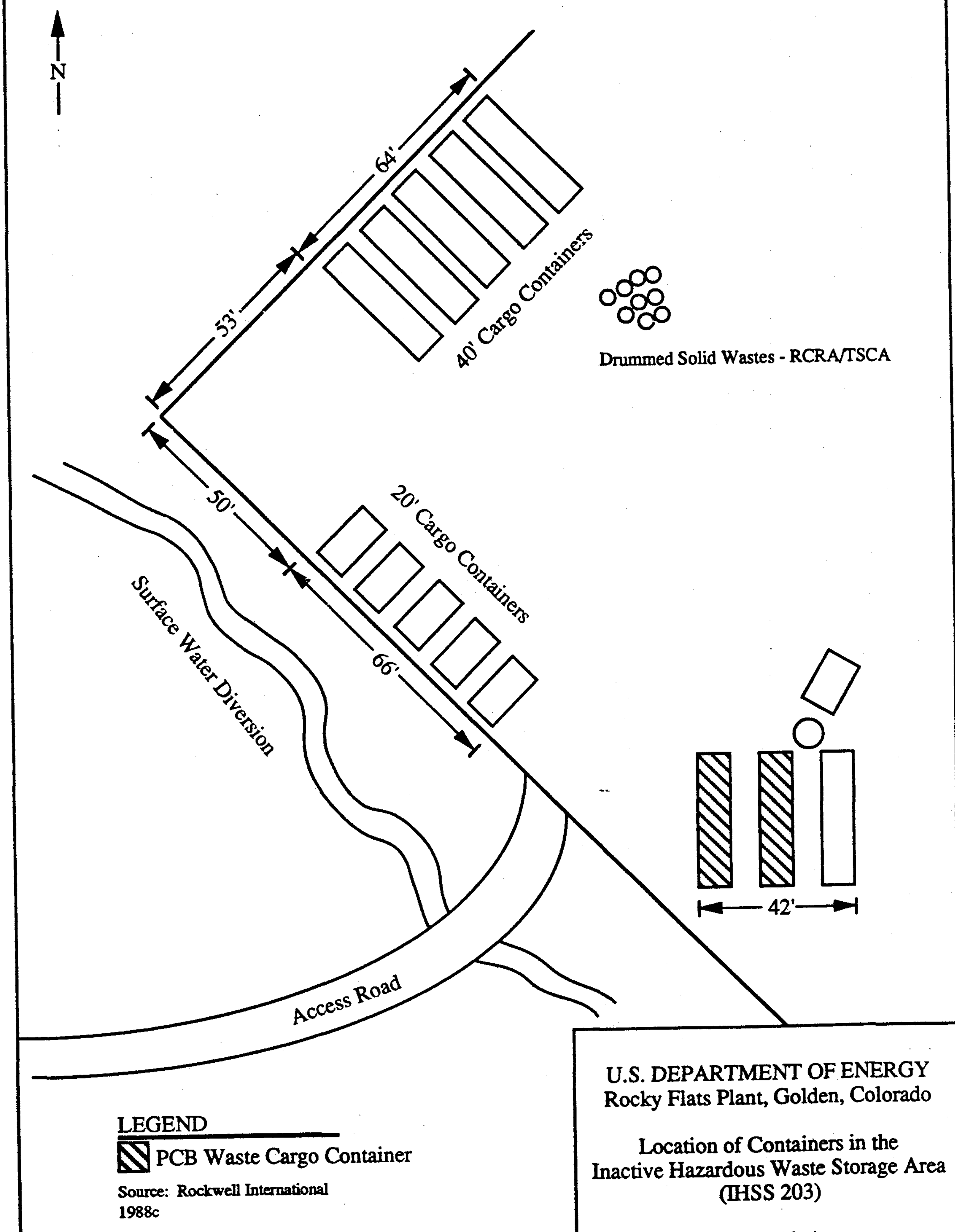
The Inactive Hazardous Waste Storage Area is located at the southwestern corner of the Present Landfill. This area was actively used from 1986 to 1987 as a hazardous waste storage area for both drummed liquids and solids (Rockwell 1988b). Fifty-five-gallon containers with free liquids were stored in fourteen cargo containers. One additional container was used to store spill control items such as oil sorbent and sorbent pillows.

During maximum inventory, the hazardous waste area consisted of eight 20-foot-long cargo containers, each capable of holding eighteen 55-gallon drums, and six 40-foot-long cargo containers, each capable of holding forty 55-gallon drums. Fifty-five-gallon drums were placed and conveyed in the cargo containers on rollers constructed of aluminum. Two conveyors extended the full length of the cargo container. A 3-foot-wide aisle extended down the center of the cargo container to permit access and inspection. The rollers elevated the drums approximately 2 inches above the catch basin floor. The approximate location of the storage containers in IHSS 203 during maximum inventory is shown in Figure 2-4 (Baker 1988).

The cargo containers were modified to meet the requirements for secondary containment in accordance with 6 CCR 1007-3 Section 264.175. Containers were fitted with signs, air vents, electrical grounding, and locks. A catch basin, constructed of 11-gauge steel with a welded steel rim and a minimum height of 6 inches, was placed within each cargo container to contain spills. The basins, as designed, were capable of containing at least 10 percent of the total volume of hazardous waste. The largest container stored in these cargo containers was 55 gallons. Drummed solids (in 55-gallon containers) were placed outside the cargo containers on the ground surface.

Total liquid storage capacity for the fourteen cargo containers was 21,120 gallons. Maximum inventory recorded for all wastes, including solids, is unknown (Rockwell 1988b). Because wastes were transferred between drums for consolidation, small spills may have occurred. However, no spills greater than reportable quantities occurred in this area during transfer operations (Rockwell 1988b).

RCRA-listed wastes were stored in twelve of the fourteen cargo containers and included solvents, coolants, machining wastes, cuttings, lubricating oils, organics, and acids. No information is available regarding the separation of waste types between the individual cargo containers. Two of the 20-foot-long cargo containers also were used to store soil and debris contaminated with polychlorinated biphenyl (PCB) as well as PCB-contaminated oil from transformers taken out of service (Baker 1988). During the first week of May 1987, all cargo containers were removed from the Inactive Hazardous Waste Storage Area. Hazardous materials are no longer stored at the site.



U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

Location of Containers in the
Inactive Hazardous Waste Storage Area
(IHSS 203)

Figure 2-4

M65\WM\ou7 Exposure Fig 2-4.mdw\11-19-92

2.3 Physical Setting

The natural environment of RFP and vicinity is influenced primarily by its proximity to the Front Range of the Southern Rocky Mountains. RFP is located less than 2 miles east of the north-south trending Front Range and approximately 16 miles east of the Continental Divide. This transition zone between prairie and mountains is referred to as the Colorado Piedmont section of the Great Plains Province (Thornbury 1965, Hunt 1967). The Colorado Piedmont is an area of dissected topography reflecting folding and faulting of bedrock along the edge of the Front Range uplift, subsequent pediment erosion and burial by fluvial processes, and more recent incision of drainages and removal of portions of the alluvial cap. Rocky Flats is the most extensive pediment surface in the area. RFP occupies the eastern edge of this pediment, which extends approximately 5 miles northeast from the mouth of Coal Creek Canyon. The surface of the Rocky Flats plain lies at an elevation of approximately 6,000 feet above mean sea level. In eastern portions of RFP, the gently sloping pediment gives way to low, rolling hills.

Three intermittent streams drain RFP, with flow toward the east or northeast. These drainages are Rock Creek, Walnut Creek, and Woman Creek. Rock Creek drains the northwestern corner of RFP and flows northeast through the buffer zone to its offsite confluence with Coal Creek. An east-west trending interfluve separates the Walnut and Woman Creek drainages. North and South Walnut Creeks and an unnamed tributary drain the northern portion of the protected area. These three forks of Walnut Creek join in the buffer zone and flow toward Great Western Reservoir, which is approximately one mile east of the confluence. Flow is currently routed around Great Western Reservoir by the Broomfield Diversion Canal operated by the City of Broomfield. Woman Creek drains the southern RFP buffer zone and flows eastward to Mower Reservoir and Standley Lake.

2.4 Meteorology

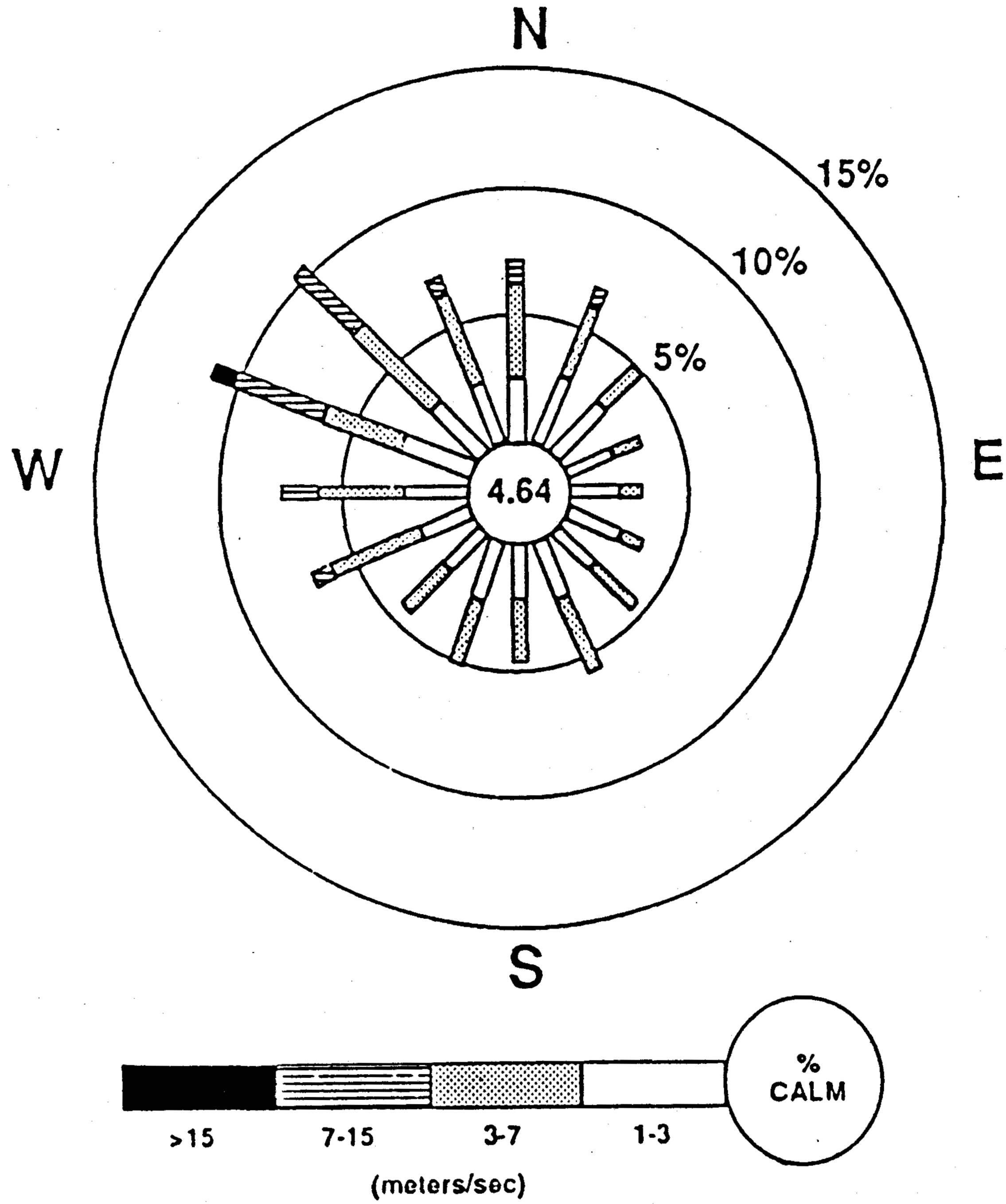
The region has a highly continental, semi-arid climate. Mean annual precipitation of the RFP vicinity is approximately 18 inches. More than half of this total occurs as snowfall, which averages approximately 85 inches per year. Approximately 40 percent of the annual precipitation occurs in the spring, which is characterized by occasional heavy snow and periods of steady rain. Precipitation gradually declines through the summer, usually occurring as brief but occasionally intense thunderstorms. Approximately 75 percent of the total annual precipitation occurs during the 180-day growing season. Relative humidities are generally low throughout the year, with an annual average of approximately 50 percent. Annual free-water evaporation is approximately 45 inches (DOE 1992), which is approximately 2.5 times the annual precipitation.

Temperatures at RFP exhibit large diurnal and annual ranges. Average minimum and maximum temperatures recorded at locations near RFP (Boulder and Lakewood, Colorado) are approximately 19°F and 45°F in January, and 59°F and 88°F in July. Temperatures as low as -25°F and as high as 105°F have been recorded at these monitoring locations. The mean annual temperature for Boulder and Lakewood is approximately 51.5°F (NOAA 1991).

RFP is noted for its strong winds. Gusty winds frequently occur with thunderstorms and the passage of weather fronts. The highest wind speeds occur during the winter as westerly windstorms known as "chinooks." The windstorm season at RFP extends from late November into April; the height of the season usually occurs in January. Windstorms at RFP typically last 8 to 16 hours and are very gusty in nature. RFP experiences wind speeds exceeding 75 mph in almost every season; gusts exceeding 100 mph are experienced every three to four years (Hodgin 1990). Northwesterly wind directions and wind speeds under 7 meters per second (m/sec) are the predominant conditions at RFP (1 mph = 0.447 m/sec). Moderately strong northerly or southerly winds are common in winter and summer, respectively, and easterly winds ("upslopes") may be associated with snowfall. The 1990 wind rose for RFP is shown in Figure 2-5. Mean wind speed for 1990 was 4.0 m/sec. The frequency of occurrence of atmospheric stability during 1990, in terms of Pasquill stability classes, was: 50.1 percent for neutral stability classes (Class D), 42.5 percent for stable classes (Class E and F), and 7.37 percent for unstable classes (Class A, B, and C).

2.5 Geology

The description of the geology in the vicinity of OU7 is derived from previous studies performed at the site. Much of the information has been summarized from the Present Landfill Hydrogeologic Characterization Report (Rockwell 1988c). Additional information



U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

Wind Rose for the
Rocky Flats Plant 1990 Annual

Figure 2-5

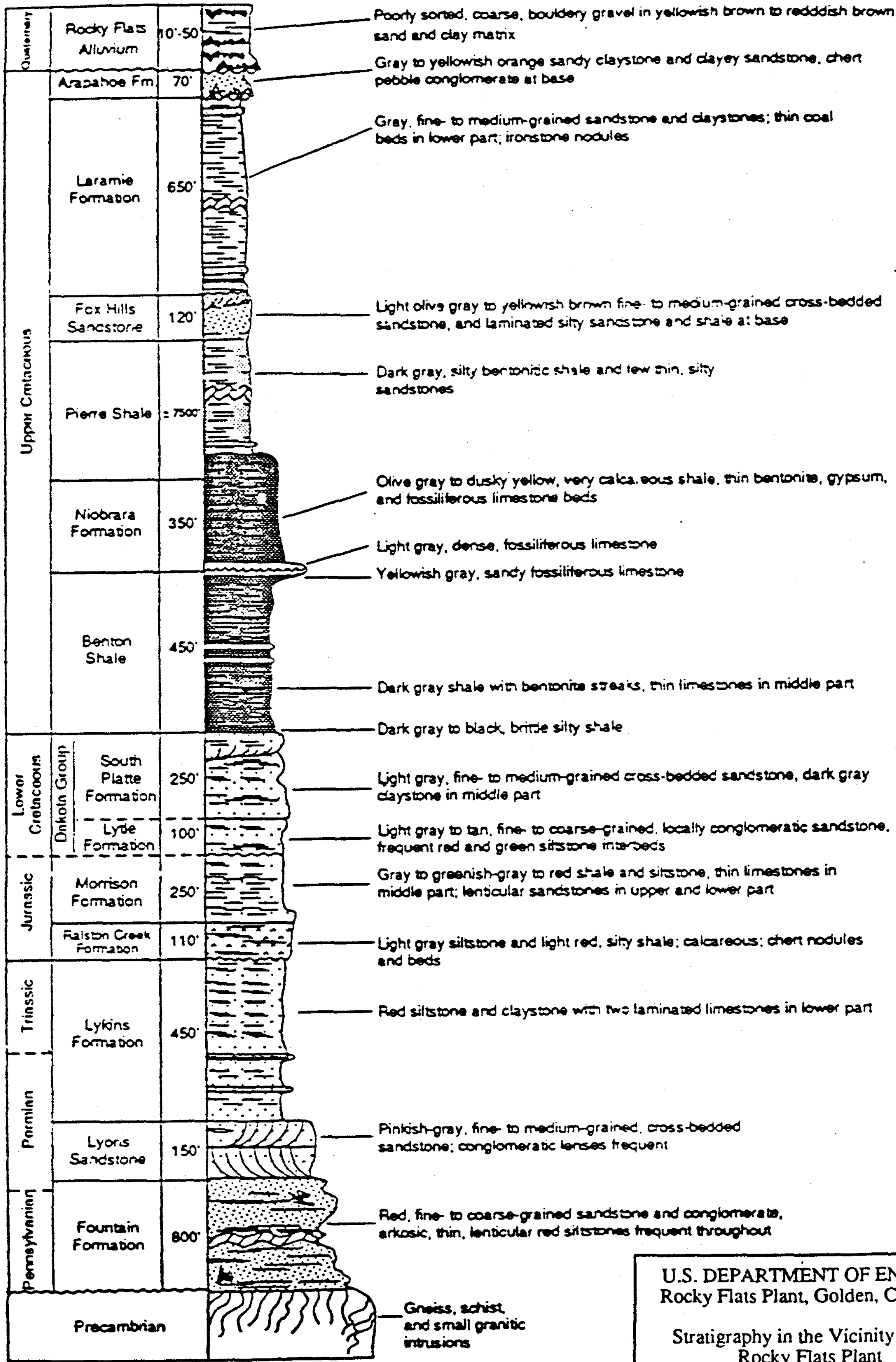
was obtained from data generated during the 1989 borehole drilling and well installation program and from the Draft Phase II Geologic Characterization Report (EG&G 1991a). The surficial geology map presented as Figure 2-6 is based on the surficial geology map presented in the 1988 Hydrogeologic Characterization Report, with recent field confirmation. Stratigraphy in the vicinity of RFP is shown in Figure 2-7.

2.5.1 Surficial Geology

Four distinct surficial deposits of Quaternary age are present in the vicinity of OU7: Rocky Flats Alluvium, colluvium (slope wash), valley-fill alluvium, and artificial fill or disturbed ground. These surficial deposits unconformably overlie the bedrock units. Rocky Flats Alluvium caps the interfluves (divides) north and south of the unnamed tributary to North Walnut Creek. As described previously, OU7 is located near the upper (western) end of this drainage. Colluvium covers the hillsides down to the drainage. Valley-fill alluvium is present along the channel of the unnamed tributary. The erosional surface on which the alluvium was deposited slopes gently eastward, truncating the Arapahoe and Laramie Formations. Artificial fill or disturbed surficial materials are present within the boundaries of the landfill, along man-made drainages surrounding the landfill, and northwest of the landfill. These surficial materials are described below.

Rocky Flats Alluvium. The Rocky Flats Alluvium is the oldest alluvial deposit present at RFP. In the area of the landfill, Rocky Flats Alluvium is described as poorly sorted, unconsolidated, and composed of clay, silt, sand, and gravel. Deposits of Rocky Flats Alluvium occur at a level approximately 200 feet above the level of modern creek beds including the unnamed tributary that drains the landfill area. Drill core logs from the landfill show thicknesses of Rocky Flats Alluvium ranging from 6.5 to 27.2 feet.

Colluvium. Colluvial materials cover hillsides along drainages that dissect the Rocky Flats Alluvium, including the unnamed tributary in which the landfill is located. the colluvium consists of poorly consolidated clay with common occurrences of silty clay, sandy clay, and gravelly clay. None of the monitoring wells at the landfill is completed in colluvial materials. In the areas that have been drilled, the thickness of colluvial deposits ranged from 3.0 to 7.1 feet.



Source: LeRoy and Weimer, 1971

U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

Stratigraphy in the Vicinity of the Rocky Flats Plant

Figure 2-7

Valley-Fill Alluvium. The most recent deposit in the landfill area is valley-fill alluvium along the floor of the unnamed tributary channel. The unconsolidated valley fill consists of poorly sorted sand and gravel in a silty clay matrix. The valley-fill alluvium is derived from reworked and redeposited older alluvial and bedrock materials. Valley-fill alluvium was noted in five of the locations drilled east of the landfill, its thickness ranged from 0.9 to 6.2 feet.

Artificial Fill. Two types of artificial fill are present in the vicinity of the landfill. The first type is derived from the excavation of Church Ditch (located northwest of the landfill) and materials used to construct the dam that forms the East Landfill Pond. The core of the East Landfill Pond dam was constructed with compacted clay and claystone. The outer shell of the dam consists of clayey sands and gravels. Materials used to construct the groundwater intercept system (clay, coarse sand, and gravels) have also been encountered during drilling of a downgradient well.

The second type of artificial fill consists of waste and cover-soil materials. This fill is described as a mixture of clay, sand, and gravel containing asphalt, insulated wire, wood, construction ribbon, surgical gloves, saranex suits, and other materials associated with RFP landfilling activities. Thicknesses of landfill materials at drilling locations range from approximately 1.5 to 23.3 feet. A previous investigation by Woodward-Clevenger (1974) reported fill at a thickness of 27 feet (Rockwell 1988a). Although the reported thickness seems reasonable, logs from the Woodward-Clevenger report were not available to validate this thickness.

2.5.2 Bedrock Geology

The Upper Cretaceous Arapahoe and Laramie Formations unconformably underlie surficial materials in the vicinity of the Present Landfill. The Arapahoe Formation is composed primarily of sandstones, siltstones, and claystones that are very similar lithologically to those in the underlying Laramie Formation. This similarity between the upper Laramie and Arapahoe has resulted in confusion distinguishing these two units. In the vicinity of the landfill, the base of the Arapahoe Formation occurs at elevations between 5920 and 5960 feet above mean sea level (EG&G 1992a). Only the lowest 20 feet of the Arapahoe

Formation is present in the vicinity of the landfill and the Arapahoe Formation is not present where the bedrock has been eroded to lower stratigraphic levels along stream drainages.

The Laramie and Arapahoe Formations in the vicinity of the landfill are lithologically very similar. As a result, the well logs frequently contain inaccurate stratigraphic designations, even though lithologic descriptions are correct. Therefore, the bedrock lithology is described below without reference to formal stratigraphic nomenclature.

Seventeen wells have been completed in various zones of the bedrock during previous drilling and well installation programs. Bedrock units in this area consist of claystone frequently interbedded with siltstones and, occasionally, with sandstones. Contacts between contrasting lithologies are both gradational and sharp. Weathered bedrock was encountered directly beneath surficial materials in all of the boreholes drilled during previous investigations at the landfill. Weathering has been observed to penetrate up to approximately 30 feet into the bedrock. A thin shale layer interbedded with coal seams was noted on one borehole log at 13.8 to 15.0 feet below ground surface, and six distinct lignite layers were noted on another borehole log. These layers range in thickness from 0.3 to 1.7 feet and are interspersed at depths from 66.6 to 252.2 feet below ground surface.

Laramie/Arapahoe Claystone. Claystone was the most frequently encountered lithology in the bedrock immediately below the Quaternary/Cretaceous angular unconformity. Claystones present in the area are described as massive and blocky, containing occasional thin laminae and interbeds of sandstone and siltstone. Borehole logs indicate occasional vertical to subvertical fractures in both the unweathered and weathered claystones. Leaf fossils and black organic matter are commonly present within the claystone.

Laramie/Arapahoe Sandstone and Siltstone. During drilling, sandstones were encountered in the bedrock in fourteen wells. The sandstones were of variable thickness (0.2 to 40.5 feet) and occurred at depths from 7.5 to 251.5 feet. In general, sandstone beds are less than 10 feet thick with thicker sections of sandstone occurring at depths greater than 100 feet. Sandstones in the landfill area are described as composed of moderately to well sorted, subrounded to rounded, very fine- to medium-grained quartz sand. The sandstones are more commonly cemented at depth where they remain unweathered. Cementing agents in the sandstones are predominantly argillic with minor calcium carbonate and silica cement noted. Weathered sandstone is lithologically similar to the unweathered sandstone. During drilling, sandstones were encountered directly underlying surficial deposits in five wells. Thicknesses of these sandstones range from 0.2 to 6.5 feet. The sandstones are generally clayey in nature and are underlain by sandy claystones or claystones.

Shallow sandstones (within 15 feet of the Quaternary/Cretaceous unconformity) were encountered while drilling three wells. Thicknesses of the shallow sandstone beds range from 0.3 to 11 feet. The shallow sandstone beds encountered while drilling two of the wells were not fully penetrated.

During drilling, siltstones associated with the claystones and sandstones were encountered in five wells and had variable thicknesses (2.1 to 33 feet) and depths (34.5 to 177.8 feet). The siltstones are described as gradational units of clayey siltstone or sandy siltstone. Relatively homogeneous layers of unweathered siltstone were encountered while drilling wells 0986 and B207189. These siltstones are described as greenish gray to dark gray, clayey, with a trace of very fine sand, and laminated.

Results of previous investigations (Rockwell 1988a) suggested that the sandstone units beneath the landfill were continuous and possibly subcropped beneath the East Landfill Pond. These conclusions were based on an estimated regional eastward dip angle of 7 degrees for the bedrock strata and an interpretation, based on limited drill-core data, that sandstone units are laterally continuous. Recent sitewide investigations conducted by EG&G indicate that the bedrock strata dip approximately 2 degrees to the east and that the sandstone units may not be laterally continuous. Applying the 2-degree dip to the subcropping sandstones suggests that they may not subcrop beneath the East Landfill Pond as previously thought.

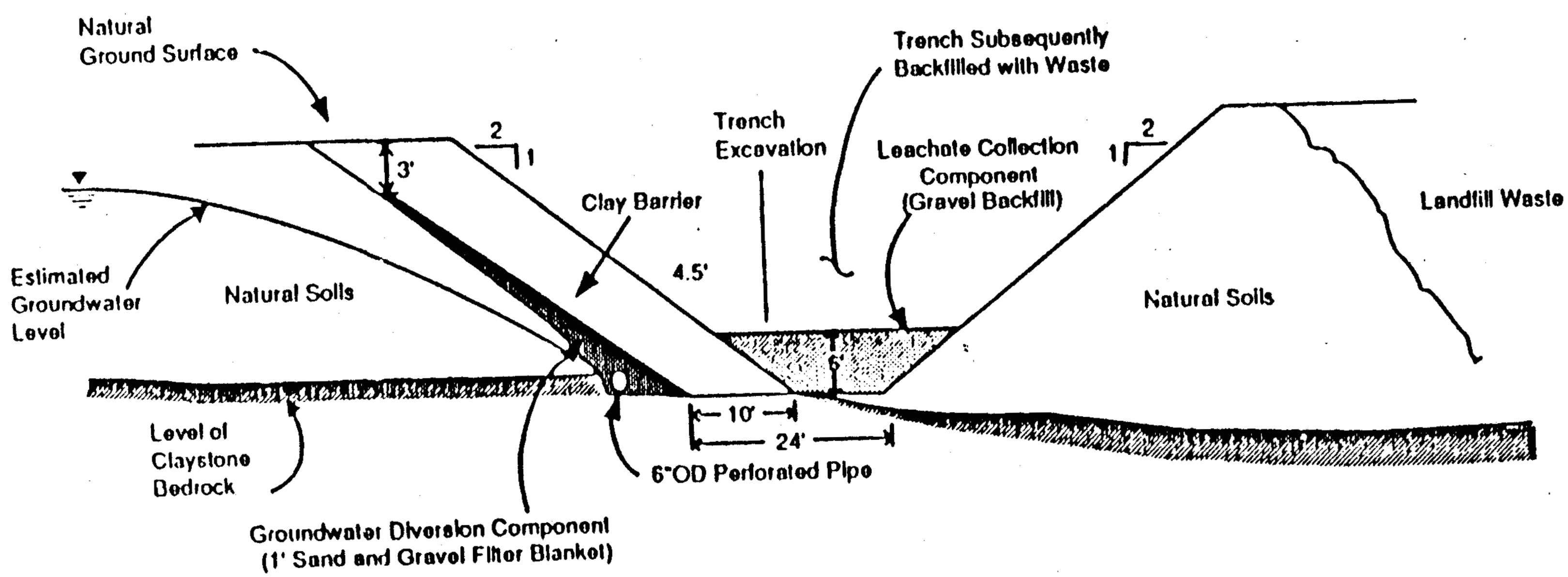
2.6 Hydrology

2.6.1 Subsurface Drainage Structures and East Landfill Pond Embankment

Subsurface Drainage Structures. A subsurface drainage control system was installed around the perimeter of the landfill in 1974 in response to the detection of tritium downstream of the landfill. The subsurface drainage system included both a leachate collection system located directly beneath the landfill wastes and a groundwater intercept system constructed between the surface water interceptor ditch and the landfill wastes. The leachate collection system was designed to collect and discharge leachate generated by the landfill and to lower fluid levels within the landfill. Leachate was discharged into Pond #1. The groundwater diversion system was designed to intercept and divert groundwater flow around the landfill. This system also provided an expanded disposal area.

The two-part system was constructed by excavating around the perimeter of the landfilled wastes to depths of 10 to 25 feet. The trench excavation for the system was 24 feet wide at the base, as shown in Figure 2-8.

The groundwater collection and diversion portion of the system was installed on the side of the trench away from the landfill waste. This system consisted of a 1-foot-thick sand and gravel filter blanket installed along the trench face. This filter blanket drain was designed to intercept groundwater and drain to a 6-inch-diameter perforated pipe installed in the bottom of the trench. The intercepted groundwater could then be discharged to Pond #1, the East Landfill Pond, or to surface drainage downslope of the East Landfill Pond. Control of discharge was accomplished by a series of valves. A 4.5-foot-thick clay barrier was placed on top of the sand and gravel filter blanket to separate the groundwater intercept system from the leachate collection system. The as-built sections and profile sheets indicate the bottom of the system to be above the bedrock surface approximately halfway between Wells B106089 and 6587 on the south side of the intercept system and approximately halfway between Wells B106089 and 6387 on the north side of the intercept system. Although the design drawings specified a 6-inch-diameter perforated pipe for the leachate collection system, as-built drawings indicate that the leachate collection system consisted of a 5-foot-thick gravel backfill placed in the bottom of the trench on the landfill



Approximate Scale: 1" = 20'
Source: Rockwell International 1988b

U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

Design Section of Groundwater Intercept and Leachate Collection System

Figure 2-8

M65\WM\ou7 exposure fig 2-8.mdw\1-14-93

side. Collected leachate drained into Pond #1, which was intended to retain the leachate without discharging to the east pond (Rockwell 1988a).

Between 1977 and 1981, the leachate collection and groundwater intercept system was buried beneath waste during landfill expansion. Lateral expansion of waste placement has resulted in wastes being located beyond the extent of the subsurface drains (Rockwell 1988a). Eastward expansion covered the points where the leachate collection system discharged into Pond #1.

Slurry Walls. Two soil-bentonite slurry walls were constructed in 1982 to extend the groundwater intercept system already in place. These slurry walls were tied into the north and south arms of the groundwater intercept system constructed in 1974. The slurry walls were constructed to reduce groundwater migration from the north and south into the landfill as it expanded to the east. Details of the connection in the design drawings indicate that the west end of each slurry wall intersects but does not break the groundwater intercept system. At these intersections, the existing drainpipe was replaced with ductile iron pipe, which was joined with the existing drainpipe using mechanical compression joints. These sections of ductile iron pipe and the joints at each end were then encased with concrete poured against undisturbed bedrock at the bottom of the excavation. This concrete block interrupted the hydraulic continuity of the sand and gravel filter blanket located outside of the clay barrier, and the only hydraulic connection of the groundwater diversion drain across the slurry trench was through the new segment of pipe. As a result, if these pipes were to be damaged or clogged, there would be no outlet from the groundwater intercept system. The slurry walls extend eastward approximately 700 feet from these points of intersection. Based on as-built drawings, the slurry walls vary in depth from 10 to 25 feet.

East Landfill Pond Embankment. As mentioned above, two ponds were constructed as part of the interim response measure to control leachate generated by the landfill. These ponds were formed by constructing temporary berms in the drainage immediately downstream of the landfill. Both ponds were approximately 0.5 acres in size. Pond #1 impounded leachate generated by the landfill. Pond #2 provided a back-up system for any overflow from Pond #1 and was also used to collect intercepted groundwater, as needed.

In 1974, a new embankment was constructed for Pond #2 (the East Landfill Pond) in approximately the same location as the original dike. The new embankment was an engineered dam structure with a spillway designed to retain the majority of the water in the channel. A low-permeability clay core keyed into bedrock was constructed within the embankment to reduce seepage. The remaining shell of the embankment was constructed of more permeable silty to clayey granular soils. The East Landfill Pond is approximately 2.4 acres in size.

2.6.2 Groundwater System Flow

Groundwater moves through two types of material in the area of the landfill: surficial material (Rocky Flats Alluvium, colluvium, valley-fill alluvium, and artificial fill), and the bedrock claystones, siltstones, and sandstones. Although discussed separately below, these two flow systems are hydraulically connected and exhibit relatively steep downward gradients that may potentially affect downward transport of contaminants. The "uppermost aquifer" at OU7 is composed of surficial materials and the weathered portion of the bedrock. This discussion is based on Rockwell (1988c) and more recent groundwater level data presented by Rockwell (1989) and EG&G (1990a and 1991c).

Groundwater is present in surficial materials at the Present Landfill under unconfined conditions. Recharge of shallow groundwater occurs as infiltration of incident precipitation and, in some areas, spray water from the landfill pond (intermittent spraying is conducted to enhance evaporation of pond water).

2.6.3 Surface Water Flow

Surface water at RFP is currently managed and monitored in accordance with a surface water management plan (EG&G 1991d). The surface water management program, which includes a National Pollutant Discharge Elimination System (NPDES) permit, is designed to protect public health and the environment from chemicals potentially occurring in surface water. This program approved by the EPA, provides for the treatment of surface water, as necessary, prior to release from the RFP.

The Present Landfill area is drained by an east-flowing unnamed tributary to North Walnut Creek. The East Landfill Pond, located immediately downstream of the Present Landfill on the unnamed tributary, collects both surface runoff and leachate from the landfill. The unnamed tributary joins North and South Walnut Creeks approximately 0.7 mile downstream of the eastern boundary of the plant security area before flowing off site.

The surface of the landfill is generally poorly drained. Based on the topography shown in Figure 2-2, the average ground surface slope across the landfill is approximately 1.5 percent (downward to the east). The ground surface is irregular and hummocky, which impedes surface drainage. Standing water collects in many areas during precipitation and snowmelt. Surface flow to the landfill is controlled by a perimeter interceptor ditch constructed around the north, west, and south sides of the landfill during 1974. This ditch is 3-feet-deep, trapezoidal in cross-section, and has a 5-foot bottom width. The north and south branches of the ditch discharge into natural drainage features that drain to points downslope of the East Landfill Pond embankment.

The landfill pond is recharged by groundwater and surface runoff from the landfill and surrounding slopes to the north and south. However, surface water/groundwater interactions have not been quantified on the hillsides north and south of the landfill pond. Water loss from the pond consists of natural evaporation, which is enhanced by spraying water through fog nozzles over the pond and on the hillside to the south. The pond reportedly does not directly discharge surface water to the drainage downgradient (Rockwell 1988a).

2.7 Ecology

2.7.1 Vegetation

RFP is located immediately below the elevation at which plains grasslands grade abruptly into lower montane (foothills) forests. The present vegetation of Rocky Flats is dominated by mixed prairie showing some residual influence of previous grazing (see Marr 1964, Clark et al. 1980). Prevalent upland grasses include blue grama, prairie junegrass, western wheatgrass, Canada bluegrass, and native Kentucky bluegrass. Some sites support remnants of midgrass and tallgrass prairie, including little bluestem, big bluestem, switchgrass, yellow Indiangrass, green needlegrass, needle-and-thread, and side-oats grama. Fringed sage, prairie sage, and common sage are locally abundant. Snowberry and wild rose may also be prevalent. Valley floors and seeps on adjacent slopes support various wetland communities ranging from sedges, rushes, or cattails to stands of mature cottonwoods and willows. The drainages also contain scattered clumps of wild plum, chokecherry, hawthorn, golden currant, and leadplant. Sideslopes of the deeper ravines contain skunkbrush and ninebark, two shrub species more characteristic of the lower foothills.

Weedy forbs and cheatgrass are locally prominent in disturbed or heavily grazed sites. Introduced pasture grasses, including smooth bone, intermediate wheatgrass, and crested wheatgrass, are present where attempts have been made to improve degraded range. Yucca and cacti are conspicuous in areas of prior heavy grazing and on sites with shallow, rocky soils. Individuals or small clumps of ponderosa pine occur on some rock outcrops.

2.7.2 Wildlife

As in most of the Front Range Urban Corridor, the wildlife of Rocky Flats has been greatly influenced by the increase in human activity and disturbance over the past 100 years. Most notable have been reductions in the number and diversity of ungulates (hoofed animals) and predators. However, the relative isolation and habitat diversity of Rocky Flats have resulted in a fairly rich animal community.

The Rocky Flats EIS (DOE 1980) reported that eight species of small mammals were captured during a live-trapping program in 1975. These species were listed as the deer mouse, harvest mouse, meadow vole, thirteen-lined ground squirrel, northern pocket gopher, hispid pocket mouse, silky pocket mouse, and house mouse. More recent studies have documented the occurrence of prairie voles, western jumping mice, and meadow jumping mice and clarified that both the plains harvest mouse and western harvest mouse are present. White-tailed jackrabbits and cottontails are also present onsite. The most abundant large mammal is the mule deer, with an estimated population of over one hundred. Carnivores present include coyotes, red foxes, raccoons, badgers, long-tailed weasels, and striped skunks.

personnel to verify their jurisdictional status. These wetlands consist of emergent, intermittently flooded stream channels and artificial, semipermanent ponds (wetland types PEMW and POWKF, respectively; see FWS 1979). Wetlands along the drainage in most areas of RFP are dominated by a narrow band of cattails, leadplant, or coyote willows with emergent trees. The latter include plains cottonwoods, hybrid (lanceleaf) cottonwoods, white poplars, peachleaf willows, and Siberian elm. Russian-olives are also common.

3.0 POTENTIALLY EXPOSED RECEPTOR POPULATIONS

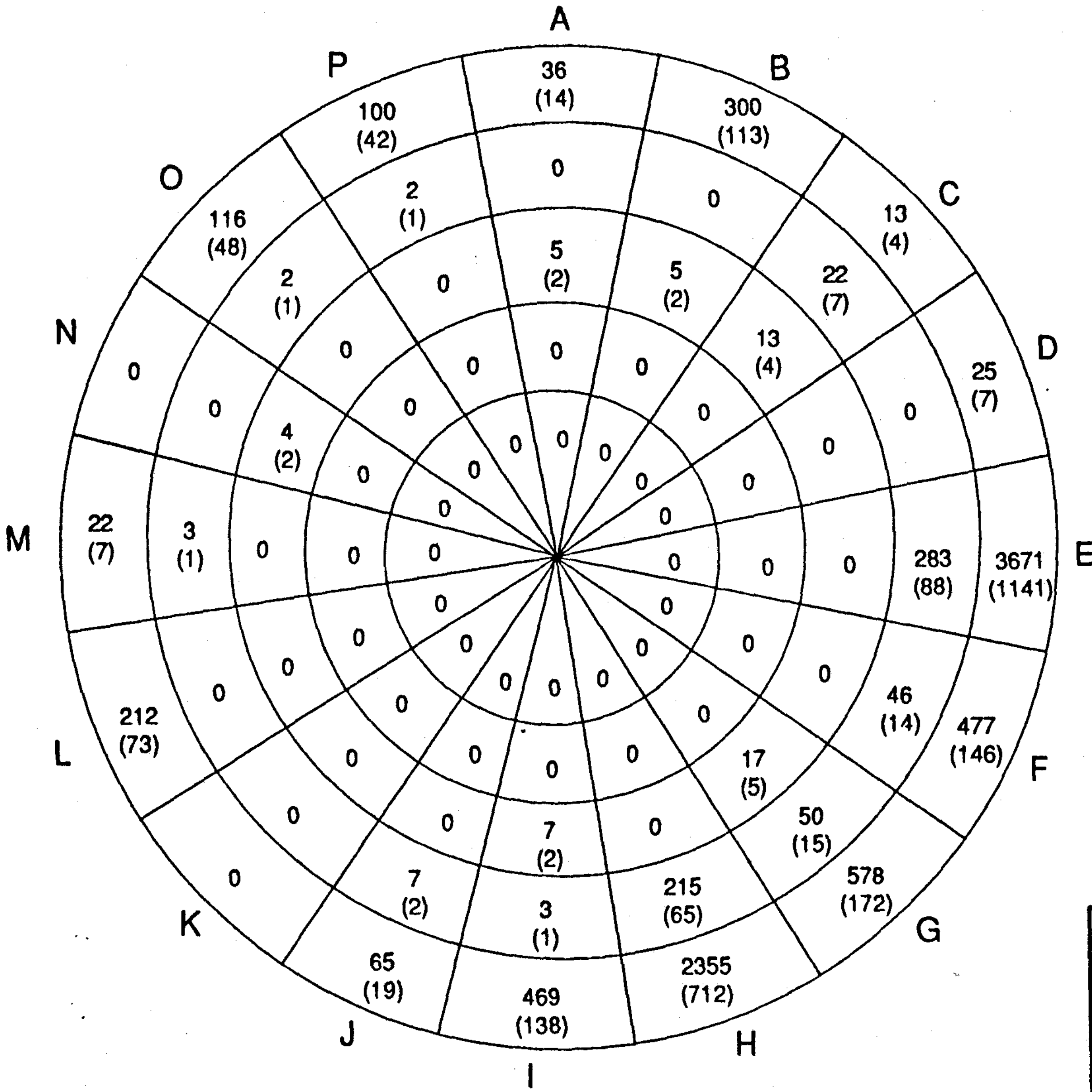
The "*1989 Population, Economic, and Land Use Data for Rocky Flats Plant*" (DOE 1990) was used to characterize land use and population distributions around the plant site. This study encompassed an area with a radius of 50 miles of area from the center of RFP and included all or part of 14 counties and 72 incorporated cities, with a 1989 combined population of 2,206,550. The study projected populations through the year 2010.

3.1 Demographics

RFP is located on a 6,550-acre parcel of federally owned land in a rural area of Jefferson County, approximately 16 miles northwest of Denver and 10 miles south of Boulder. The plant facility is located near the center of the parcel and is surrounded by a buffer zone of approximately 6,150 acres. The area west of RFP is mountainous, sparsely populated, and primarily government-owned. The area east of RFP is generally a high, semi-arid plain, densely populated, and privately owned. Most of the population included in the DOE study is located within 30 miles of RFP, primarily in the Denver metropolitan area to the east and southeast.

Most of the development near RFP has occurred since the plant was built, with future development expected to continue (DOE 1992). Approximately 316,000 people reside within a 10-mile radius. The most significant development is located to the southeast, in the cities of Westminster, Arvada, and Wheat Ridge. The cities of Boulder to the northwest; Broomfield, Lafayette, and Louisville to the northeast; and Golden to the south also contain significant developments within this 10-mile radius (DOE 1992).

Figure 3-1 (taken from DOE 1990) illustrates the distribution of the residential population within a 5-mile radius of RFP in 1989. The projected residential population for the year 2010 is illustrated in Figure 3-2 (DOE 1990). Sectors (circumferences) 1 and 2 represent land within the RFP boundary and therefore are relevant to onsite scenarios. Sectors 3, 4, and 5 mostly include property outside the RFP boundary and thus are relevant to offsite scenarios. Radial Segments D through I, which lie in the predominant downwind directions



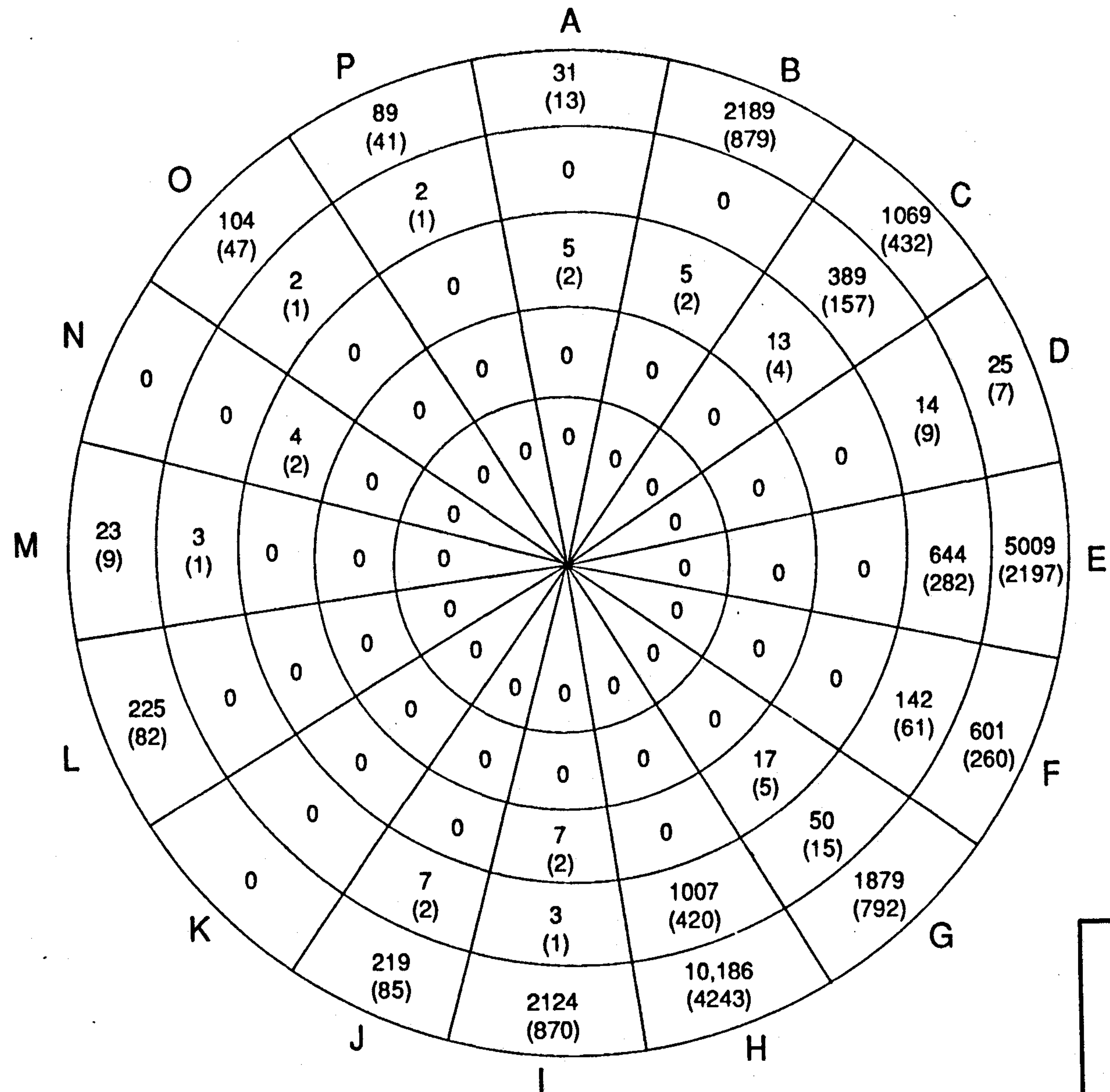
Miles	Sector Name
0-1	Sector 1
1-2	Sector 2
2-3	Sector 3
3-4	Sector 4
4-5	Sector 5

SOURCE: DOE, "1989 POPULATION, ECONOMIC AND LAND USE DATA BASE FOR ROCKY FLATS PLANT",

U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

1989 Populations
(and Households),
Sectors 1-5

Figure 3-1



Miles	Sector Name
0-1	Sector 1
1-2	Sector 2
2-3	Sector 3
3-4	Sector 4
4-5	Sector 5

SOURCE: DOE, "1989 POPULATION, ECONOMIC AND LAND USE DATA BASE FOR ROCKY FLATS PLANT",

U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

2010 Populations (and Households), Sectors 1-5

Figure 3-2

from OU7, represent the primary areas relevant to upward exposure pathways. The 1989 and projected 2010 population data shown in Figures 3-1 and 3-2 are summarized in Table 3-1. The information presented in Table 3-1 indicates that zero population growth is projected in the next 18 years for areas immediately adjacent to the RFP boundary (Sector 3).

The school closest to RFP is Witt Elementary School, approximately 2.7 miles east of the buffer zone (EG&G 1991b). All other sensitive subpopulation facilities (e.g., hospitals and nursing homes) are located beyond the 5-mile radius from the center of RFP. Ninety-three schools, eight nursing homes, and four hospitals occur within a 10-mile radius of RFP (DOE 1992).

The nearest drinking water supply is Great Western Reservoir, located approximately 2.3 miles east of the center of RFP. The City of Broomfield operates a water treatment facility immediately downstream from Great Western Reservoir. This facility supplies drinking water to approximately 28,000 persons. Standley Lake Park, a recreational area and a drinking water supply for the cities of Thornton, Northglenn, Westminster, and Federal Heights, is located 3.5 miles to the southeast of RFP. From Standley Lake, water is piped to each city's water treatment facility. Boating, picnicking, and limited overnight camping are permitted at Standley Lake Park.

3.2 Offsite Land Use

3.2.1 Current

Current land use in the area surrounding RFP is shown in Figures 3-3 and 3-4. Table 3-2 is a summary of land use corresponding to the Jefferson County Land Use Map. In general, current land use surrounding RFP includes open space (recreational), agricultural, residential, and commercial/industrial. Northeastern Jefferson County, including RFP, is one of the most concentrated areas of industrial development in the Denver metropolitan area (Jefferson County 1989).

Table 3-1 Current And Projected Population
In The OU7 Exposure Assessment Area

Year 1989/2010						
Sector	D	E	F	G	H	I
1	0/0	0/0	0/0	0/0	0/0	0/0
2	0/0	0/0	0/0	0/0	0/0	0/0
3	0/0	0/0	0/0	17/17	0/0	7/7
4	0/14	283/644	46/142	50/50	215/1007	3/3
5	25/25	3671/5009	477/601	578/1879	2355/10186	469/2124

Source: DOE 1990. *1989 Population, Economic, and Land Use Data for Rocky Flats Plant*.

Table 3-2 Rocky Flats Plant OU7 Current Surrounding Land Use In Jefferson County

Parcel #	Current Use/ Project Name	Zoning[1]	Land Use Type
22009			
44001	Vacant	A-2	Vacant
44002			
44003	Vacant	I-1	Industrial
44004	Vacant	A-2	Vacant
44005			
44006	Vacant	I-3	Industrial
44007	Vacant	A-2	Vacant
45001			
45002	Walnut Creek Unit 1	P-D	Single Family - Detached
45002	Walnut Creek Unit 1	P-D	Retail
45003	Vacant	A-2	Vacant
45004	Single Family - Detached	A-2	Single Family - Detached
45005	Single Family - Detached	A-2	Vacant
45006	Water	A-2	Water
45007	Single Family - Detached	A-2	Single Family - Detached
45007	SF-D	A-2	Farm/Ranching
46005	Vacant	A-2	Single Family - Detached
46006	Triple C Quarter Horses	A-2	Retail
46007	Horse Barn- Boarding & Breeding	A-2	Retail
46008	Single Family - Detached	A-1	Single Family - Detached

Table 3-2 Rocky Flats Plant OU7 Current Surrounding Land Use In Jefferson County (cont.)

Parcel #	Current Use/ Project Name	Zoning[1]	Land Use Type
22009			
46009	Single Family - Detached	SR-2	Single Family - Detached
46011	Mountain View Tech Center	P-D	Industrial
46012	Jefcope	P-D	Industrial
46017	Water	A-2	Water
46019	Single Family - Detached	A-2	Single Family - Detached
47036	Vacant	SR-2	Single Family - Detached
47040			
71001	Rocky Flats	A-2	Industrial
72001	Vacant	I-2	Industrial
72002	Vacant	A-2	Vacant
72003	Single Family - Detached	A-2	Single Family - Detached
72004	Vacant	I-2	Vacant
72004	Vacant	I-2	Industrial
72005	Tosco Flg 1	I-2	Industrial
72006	Rocky Flats Ind Park Flg 2	I-2	Industrial
72007	Rocky Flats Ind District Flg 1	I-2	Industrial
72008	Water Tank Ralston Val Stn 2	I-2	Utilities
72009	Vacant - Rocky Flats	A-2	Industrial
72010	Vacant	I-2	Industrial
72011	Northwest Industrial	I-2	Industrial
72012	Vacant	A-2	Vacant
72013			

Table 3-2 Rocky Flats Plant OU7 Current Surrounding Land Use In Jefferson County (cont.)

Parcel #	Current Use/ Project Name	Zoning[1]	Land Use Type
22009			
73001	Vacant	A-2	Vacant
73005	Wheat Ridge Gardens	A-2	Vacant
73019	Vacant	A-1	Vacant
73020	Single Family - Detached	SR-2	Single Family - Detached
73021	Vacant	RC	Office/Retail
73022	Westminster Gardens	A-2	Single Family - Detached
99001	Great Western Aggregate Quarry	I-1	Industrial
99005	Sawmill Operation	I-2	Industrial
99006	Great Western Aggregates	I-2	Industrial
99007	Vacant	I-2	Industrial
99008	Colorado Brick Comp Clay Mine	M-C	Mining
99009	Vacant	I-2	Industrial
100001	Rock Creek Ind Park Vacant	P-D	Industrial
100002	Vacant	I-1	Industrial
100003	Rocky Flats - Vacant	I-1	Industrial
100004	Rocky Flats - Clay Extraction	M-C	Industrial
100005	Rocky Flats - Vacant	I-2	Industrial
100006	Electric Substation	M-C	Utilities
100006	Gravel Mine	M-C	Industrial
101001	Vacant	A-2	Vacant
101002	Vacant	M-C	Industrial
101003	Vacant	I-2	Industrial

Table 3-2 Rocky Flats Plant OU7 Current Surrounding Land Use In Jefferson County (cont.)

Parcel #	Current Use/ Project Name	Zoning[1]	Land Use Type
22009			
101004	Mine and Water	I-2	Industrial
101005	Northwest Industrial	I-2	Industrial
101006	Vacant	M-C	Industrial
101007	Sanitary Landfill and Gravel	P-DA	Industrial
101008	Rocky Flats Lake	M-C	Water

1 Zoning Abbreviations are as follows:

A-1	Agricultural 1
A-2	Agricultural 2
I-1	Industrial 1
I-2	Industrial 2
I-3	Industrial 3
P-D	Planned Development
SR-2	Suburban Residential 2
RC	Restricted Commercial
P-DA	Planned Development Amended
Source:	Jefferson County

Current land use in the area relevant to the OU7 exposure scenarios (immediately southeast of RFP and OU7) includes all of the uses mentioned above. Predominant uses appear to be open space, single-family detached dwellings, and horse-boarding operations. Two small cattle herds (approximately 10 to 20 cattle in each) were observed: one to the southeast, where 96th Avenue turns into Alkire and crosses Woman Creek; and one to the east of RFP, between Alkire and Simms Streets and north of 100th Avenue. Industrial facilities within the relevant area, include the TOSCO laboratory, Great Western Inorganics Plant, and Frontier Forest Products (EG&G 1991b). All are located to the south, along Colorado Highway 72.

3.2.2 Future

Future land use generally follows existing patterns. Jefferson County (1989) developed a baseline profile of growth and land use in the area as part of a socioeconomic study of its northeastern area (*Northeast Community Profile*). As a result of this study, Jefferson County expects that industrial land uses will continue to dominate the northeastern portion of the county. Along with the increase in industrial development, the county expects income and employment growth to increase dramatically, while household and population growth is expected to increase only moderately. In other words, with industrial growth, employment opportunities are expected to increase; yet, as the land is developed for industry, the availability of land for residential development decreases. As a result, household and population growth will be limited.

Industrial and commercial development of the area is attractive to businesses and developers because of (1) the availability of undeveloped, lower-cost lands, and (2) the lower taxes associated with locating in an unincorporated portion of the county.

Both the proposed construction of highway W-470 and its alignment are uncertain. Near-term (5 years) development of the highway is unlikely. Proposed alignments have included skirting either the southern and eastern or western and northern boundaries of RFP. Commercial growth, particularly light industrious and office parks, would be expected to occur along the highway (Jefferson County 1989).

Residential development is not as attractive as industrial development of the area for several reasons, including the potential alignment of W-470, the proximity to Jefferson County Airport, and the proximity to RFP. The decreased desirability of living near a major highway or an airport, for traffic and noise reasons, is a deterrent to residential development. The proximity of RFP and the general industrial nature of the area also decreases the desirability of housing in the area.

Future land use in the area is the topic of *The North Plains Community Plan* (Jefferson County 1990). The plan is intended to serve as a guide to the county and cities to achieve compatible land use and development decisions, regardless of the jurisdiction. It was developed cooperatively by representatives of Jefferson County and five communities (Arvada, Broomfield, Golden, Superior, and Westminster) as well as a variety of interest groups, including homeowners, businesses, builders/developers, environmentalists, and special districts. The plan identifies RFP and the Jefferson County Airport as constraints to future residential development in the area and recommends office and light industrial development. It further identifies the acquisition of lands for open-space uses as a high priority for the area and recommends that large amounts of undeveloped land be provided for this purpose (Jefferson County 1990).

The North Plains Community Development Plan Study Area Summary Map (Figure 3-5) and the Jefferson Center Comprehensive Development Plan (Figure 3-6) show that the predominant future land uses south and southeast of RFP will consist of commercial, industrial, and office space. Directly to the east, land use is expected to remain open space and agricultural/vacant. Residential development is projected to occur farther from RFP than these other uses. This planning is consistent with the zero projected residential growth rate in the next 18 years for areas immediately adjacent to the RFP (DOE 1990). Projected industrial growth will place additional demands on finite resources such as water and land and will probably result in increasing costs for these resources. At some point in the future, these increasing costs are expected to make agricultural use of the land impracticable.

North of RFP in Boulder County, the predominant land uses include open space, parkland, and industrial development, as shown in Figure 3-4. Two areas adjacent to RFP have been annexed by the towns of Broomfield and Superior. These two communities have participated in the Jefferson County cooperative planning process and are planning business, industrial, and mixed-land uses for the area (City of Broomfield 1990, Jefferson County 1990, Boulder County 1991).

The information presented above indicates that current land use in the immediate vicinity of RFP is primarily commercial/industrial and that such land use will continue into the future. It is likely that the potential for residential development in this area will be impeded by the growth of business and industry that is expected to occur, and potentially by the presentation of open space.

3.3 Onsite Land Use

3.3.1 Current

OU7 is located within the buffer zone, north of the protected area. Current activities within OU7 include environmental investigations and routine security surveillance. Additionally, the present landfill continues to receive solid waste from onsite facilities. RFP is also conducting transition planning for the eventual decontamination and decommissioning (D&D) of the plant site.

3.3.2 Future

Future plans for RFP activities are discussed in the Nuclear Weapons Complex Reconfiguration Study. The two preferred reconfiguration options in the study include relocation of RFP functions (DOE 1992). Future land-use alternatives are discussed in the RFP *Final Environmental Impact Statement* (EIS) (DOE 1980). Four alternatives are addressed in the document, including the no-action alternative. These alternatives, which may be subject to change, are summarized below (DOE 1992):

- The no-action alternative involves completion of nuclear production upgrades, maintenance of production standby, and compliance with the Interagency Agreement (IAG) environmental restoration (ER) commitments.

- Alternative 1 involves nuclear production at reduced levels, compliance with IAG ER commitments, and placement of surplus facilities into safe storage. This alternative is no longer considered viable, owing to the recent decision to implement D&D at RFP.

- Alternative 2 allows nuclear production at up to 1989 levels, increased non-nuclear production, placement of surplus facilities into safe storage, and completion of ER by 2020. This alternative is no longer considered viable, for the same reason as Alternative 1.

- Alternative 3 involves transition to no production of nuclear or non-nuclear components, completion of ER by 2020, D&D of selected facilities, and placement of other facilities into safe storage.

Use of onsite production facilities by private industry is planned for the future at RFP, according to a June 12, 1992, speech by Secretary of Energy James Watkins. Watkins characterized RFP as an attractive site for manufacturers and other businesses (Denver Post 1992). Private industry could relocate to existing buildings and use existing equipment at RFP, after necessary decontamination is complete (Boulder Daily Camera 1992). One organization working to achieve this objective is the Rocky Flats Local Impacts Initiative (RFLII). This group is comprised of representatives from local businesses and government agencies and has been formed to develop a strategy to transform future changes at RFP into economic, socioeconomic, educational, land use, environmental, and infrastructural advantages. One of this group's goals is to work with the DOE and local economic development agencies to identify and attract businesses to occupy existing buildings at RFP (RFLII 1992).

When the Atomic Energy Commission (AEC) acquired the undeveloped land surrounding the production area, it established plans to preserve the land as open space (AEC 1972).

It is plausible that the buffer zone and OU7 area will be preserved as open space. The buffer zone is being considered as a potential ecological preserve or National Environmental Research Park.

> There are at least three reasons why RFP would make an exceptional environmental research area. First, the site presents an excellent sample of a shortgrass prairie/montane ecotone... Second, it also provides an almost *unique opportunity* to conduct environmental research in an area which abuts a major metropolitan area... Third, ...the site has an abundance of wetlands and would be an excellent outdoor laboratory for a variety of wetland related ecological research (Knight 1992).

Ecological surveys of the buffer zone, performed as part of the RFI/RI process and for compliance with the Endangered Species Act, have indicated the high quality of habitats at RFP and the documented or potential presence of several species of special concern. Additional surveys are ongoing to identify and provide for the protection of any threatened and endangered species at the site, if necessary (EG&G 1992b). Because the buffer zone has not been impacted by commercial development for many years, progressive re-establishment of native habitats has occurred. Thus the future use of this area as an ecological reserve is reasonable and consistent with DOE policy and plans (DOE 1992). This type of use is also consistent with the Jefferson County Planning Department's recommendations for the provision of large amounts of undeveloped land in the area (Jefferson County 1990). Extensive development of the area is also unlikely owing to the historical use of RFP, the potential for conversion of the buffer zone into an ecological preserve, and the steep topography in some areas.

The limited availability of water is also a factor affecting development of the RFP area, as with all of the Denver metropolitan area. The Denver Water Board controls most of the metropolitan water supply and currently provides much of the suburban area's water. The Denver Water Board, however, is under no obligation to supply water to the suburbs, making the future supply questionable (Jefferson County 1989). The amount of industrial development expected in the area surrounding RFP will also result in competition for water. In addition, existing facilities within RFP are already served by municipal water supplies from the City of Golden, increasing the likelihood that existing structures will be targeted for use by industry and business.

In summary, future land use will generally follow existing land-use patterns and will likely involve industrial/office or open-space uses.

3.4 Qualitative Evaluation of Potential Receptors

Current and future human population groups on and near the site are potential candidates for evaluation based on their likelihood of exposure to site-related chemicals of concern. EPA guidance does not require an exhaustive assessment of every potential receptor and exposure scenario (EPA 1992a). Rather, the highest potential exposures that are reasonably expected to occur (reasonable maximum exposures) should be evaluated, along with an assessment of any associated uncertainty (EPA 1989a).

The current pattern of land use and the likelihood of future land uses are summarized in Table 3-3. The probability of future land-scenario use is defined in terms of increasing credibility, as follows: (1) improbable (unlikely to occur), (2) plausible (conceivable, though not expected), and (3) credible (believable with reasonable grounds).

Future onsite uses for agriculture and residential communities and future offsite use as an ecological reserve are classified as improbable. Future onsite agricultural uses are considered improbable because of:

- Growth pressures on water and land resources from planned offsite development, as discussed in Section 3.2.2.

- Competition with more credible future onsite land uses (e.g., ecological reserve, industrial), as noted in Section 3.3.2.

Future onsite residential uses are classified as improbable for multiple reasons, as summarized below:

Table 3-3 Summary of Current and Future Land Uses[a,b,c]

Land Use Category	Current		Future	
	Offsite	Onsite	Offsite	Onsite
Residential	Yes	No	Credible	Improbable
Commercial/Industrial	Yes	Yes	Credible	Credible[d]
Recreational	Yes	No	Credible	Credible[e]
Ecological Reserve	No	No	Improbable	Credible[e]
Agricultural	Yes	No	Plausible	Improbable

[a] Credible is used to indicate scenarios that may reasonably occur.
[b] Plausible is used to indicate scenarios that are conceivable, though not expected.
[c] Improbable is used to indicate scenarios that are unlikely to occur.
[d] Expected in the currently developed area of the plant site.
[e] Expected in the buffer zone.

- Inconsistency with planned offsite industrial and commercial development of the area.

- Unattractiveness for residential development because of proximity to current and future industrial uses, including the RFP facilities and the Jefferson County Airport.

- Limited water resources for residential development.

- Inconsistency with proposed onsite uses for the buffer zone (e.g., ecological reserve, open space) and the current developed areas (e.g., industrial use).

Future offsite use of the immediate area surrounding RFP as an ecological reserve is designated as improbable based on:

- Projected offsite industrial and commercial development of the area.

- Unattractiveness of the area as an ecological reserve because the native habitat has been largely disturbed by current agricultural, grazing, and development activities.

Future offsite agricultural land uses are identified as plausible because it is believed that current agricultural areas will be phased out because of Front Range development and associated demands and increasing costs on land and water resources. Future offsite land uses for residential communities, commercial/industrial development, and recreational activities are identified in Table 3-3 as credible exposure scenarios. It is expected that the portion of the plant where buildings now exist will continue to be industrial, and the buffer zone will remain undisturbed due to the reasons outlined in Sections 3.2 and 3.3. These reasons are:

- Future offsite land use plans point toward industrial and open space usage around the plant.

- Private industry is expected to occupy the buildings in the industrial onsite areas.

- It would be advantageous to keep the buffer zone surrounding the industrialized onsite area as an ecological preserve/open space due to its unique nature.

- Residential development is relatively unattractive, as discussed previously.

Offsite residential, commercial/industrial, and recreational exposure scenarios are considered credible in the future because they currently exist offsite.

3.5 Receptors Selected for Qualitative Risk Assessment

As noted in Section 3.4, exposure scenarios that are more credible are more appropriate candidates for quantitative assessment in the HHRA. Additionally, where multiple scenarios are credible, not all need be analyzed, because those scenarios having less potential exposure will be bounded by those having greater potential exposure. Scenarios having a greater potential exposure may be determined based on various factors, including exposure route, exposure frequency and duration, and contact rates. Exposure scenarios selected for quantitative evaluation and the bases for their selection are presented in Table 3-4. Current onsite workers, current offsite residents, hypothetical future onsite workers, and hypothetical future onsite ecological researchers are included among the receptor scenarios to be quantitatively evaluated on the basis of their credibility and representative or bounding exposure potential. While a future hypothetical onsite resident has been shown to be improbable, this exposure scenario has also been retained for quantitative evaluation so that the full range of risks can be examined by the regulatory agencies. Each of these receptor scenarios is described in further detail below.

Exposure points for these receptors are shown in Figure 3-7. The current onsite worker and the hypothetical future onsite resident, worker, and ecological researcher are all located within the boundaries of OU7. While the hypothetical future onsite worker is a credible exposure scenario, this receptor category is more likely to have an exposure location within the existing developed area of the plant site because of its existing infrastructure of facilities and utilities. Exposure sources (e.g., landfill, soil) will be characterized by aggregating data on an operable unit basis and not on an IHSS specific basis.

Table 3-4 Current and Future Land Use Scenarios Retained for Quantitative Evaluation

Land Use Category	Current		Future	
	Offsite	Onsite	Offsite	Onsite
Residential	Quantitative[a]	None[d]	None[f]	Quantitative[i]
Commercial/Industrial	None[b]	Quantitative[e]	None[g]	Quantitative[j]
Recreational	None[b]	None[d]	None[g]	None[g]
Ecological Reserve	None[b]	None[d]	None[d]	Quantitative[j]
Agricultural	None[c]	None[d]	None[h]	None[d]

[a] This current exposure scenario exists and is retained for quantitative evaluation.
[b] This current exposure scenario is judged to be bounded by the exposure of an offsite resident on the basis of exposure frequency and duration and contact rates.
[c] Current offsite agricultural land use down wind of OU7 primarily consists of horse boarding operations and intermittent cattle grazing and is expected to bound potential exposures for the current offsite residential land use scenario.
[d] This land use category does not currently apply or is improbable in the future and thus is not quantitatively evaluated.
[e] This current scenario has low exposure potential, considering the comprehensive health and safety program at RFP, but is included for the sake of completeness.
[f] The current offsite residential exposure scenario is representative of the future offsite residential exposure potential.
[g] This future land use category is judged to be bounded by the exposure potential for other future onsite categories quantitatively evaluate on the basis of exposure frequency and duration and contact rates.
[h] Growth pressures of Front Range development on land and water resources and associated increasing costs indicate that future agricultural land use around RFP will diminish from current uses and thus need not be evaluated.
[i] This future land use scenario is improbable; however, it is retained for evaluation to ensure that the most conservative scenario is included in the evaluation.
[j] This future land use scenario is credible and is anticipated to have a high exposure potential based on exposure frequency and duration and contact rates.

3.5.1 Current Onsite Worker

EG&G Rocky Flats Plant, Inc. Health and Safety (H&S) activities at RFP are directed by the Associate General Manager for Support Operations and supported by several divisions, including Radiological Operations, Occupational Safety, Health and Safety Area Engineering, Industrial Hygiene, Radiological Engineering, and Occupational Health (EG&G 1990c). For environmental restoration work at RFP, EG&G Rocky Flats Plant, Inc. and DOE have adopted the federal Occupational Safety and Health Administration's (OSHA) standards for hazardous-waste site workers (EG&G 1990c). EG&G has superseded some of the OSHA standards with more stringent policies established by EG&G, DOE, or other governmental agencies (EG&G 1990c). At RFP, H&S programs are written for everyday activities as well as specific projects. All EG&G subcontractors must prepare their own site/project-specific H&S plans and must require and enforce standards at least as stringent as those of EG&G (EG&G 1990c).

Programs at RFP that support the H&S plans and programs include radiation protection, emergency response, occupational safety, vehicular and pedestrian safety, fire protection, and contractor safety (EG&G 1992c). The written programs contain the requirements and procedures to be followed to ensure a work environment that is free from exposure to chemical, physical, and biological hazards (EG&G 1992c). Additionally, responsibility for all aspects of compliance with the programs and plans is established, and an audit program is in place to evaluate whether compliance is in effect. RFP personnel are trained in personal hygiene and safety, use of protective clothing, and emergency response procedures. The health and safety of current workers at RFP is thoroughly monitored, with required baseline, annual, and exit physical examinations. The exposure of these workers to chemicals of concern is controlled and limited by monitoring to acceptable levels and is ensured by reporting requirements. Despite these thorough health and safety programs, the current onsite worker will be quantitatively evaluated in the human health risk assessment for the sake of analysis completeness. The present landfill worker was selected as the current onsite worker to be evaluated on the basis of his greater potential for exposure considering exposure frequency, duration, and contact rates.

3.5.2 Current Offsite Resident

The human health risk assessment will evaluate current offsite residents at existing locations, since the public is restricted from access to RFP. Present levels of security at the RFP include fencing, armed security patrols, and modern electronic security and surveillance systems. Fencing is posted to warn potential intruders that they are trespassing on federal property and, if caught, will be arrested. Plant security personnel report that there have been no incidents of trespassing in the buffer zone in the past seven years. Thus, even if trespassing were to occur at the RFP, it is highly unlikely that such events would occur repeatedly for the same individual.

This scenario will evaluate the reasonable maximum risk to the present residential population. Two existing residential locations are selected for evaluation as shown in Figure 3-7. These locations correspond to the most reasonable locations for maximum exposures based on their proximity to the site and the direction of prevailing winds. They are also expected to be representative of future residential exposures because future industrial/commercial land use plans for the area exclude the likelihood of any significant additional residential development.

3.5.3 Future Onsite Worker

The human health risk assessment will evaluate future onsite workers. Based on the future industrial development plans in the area, the worker will be assumed to be an industrial or office worker. The location of this receptor is shown in Figure 3-7. As discussed in Section 3.3.2, it is expected that desirable locations for future development of commercial facilities will be in close proximity to existing structures and utilities. Thus, the more likely location of the hypothetical future onsite worker is within the currently developed area of the plant site. However, the exposure location for this hypothetical receptor is conservatively assumed to be within the boundaries of OU7. Since the health and safety of onsite workers is presently ensured and monitored under a comprehensive health and safety program at RFP, potential exposures to current onsite workers will not be evaluated in the risk assessment. The health and safety programs and policies are discussed in more detail below.

A future onsite worker, not protected by a the current RFP health and safety program (i.e., no-action), will be quantitatively evaluated. This worker is assumed to be unprotected and untrained in health and safety matters. Based on the future industrial development plans for the area, the future onsite worker is assumed to be an industrial or office worker at an appropriate facility. This setting is likely to have extensive paved areas and well maintained landscaping. This evaluation will be performed since all future land uses point to this setting as the most probable future land use of the industrial area of RFP.

3.5.4 Future Onsite Ecological Researcher

Because the future use of onsite undeveloped areas (e.g., buffer zone) at RFP will most likely involve open space or a ecological reserve, this scenario will be evaluated for the area within OU7. The receptors in an open-space scenario would include day hikers and a research biologist/ecologist conducting area studies. Of these two potential receptors, the research biologist is likely to spend more time at the site and come in closer contact with the soils, plants, and surface water. Field work may involve kneeling or sitting on bare ground or vegetation and contacting site soils, sediments, and surface water. The day hiker would probably spend less time at the site and come in less contact with soils and surface water. Therefore, the most reasonable maximum exposure scenario in this setting is the hypothetical future ecological researcher. The area applicable to this receptor is shown in Figure 3-7.

3.5.5 Hypothetical Future Onsite Resident

The human health risk assessment will include quantification of future onsite resident exposures, though land use projections make exposures to this receptor category improbable. It is further assumed that the hypothetical future resident exposure location is within the OU7 boundaries. As with the future onsite worker, the future onsite resident would be unprotected and untrained in health and safety matters. Additionally, the future onsite resident is likely to spend the greatest amount of time at or near OU7 because of its proximity to the resident's home. Consequently, the future onsite resident scenario will represent the maximum frequency, duration, and level of exposure among the receptor categories evaluated.

4.0 EXPOSURE PATHWAYS

This section discusses the potential release and transport of chemicals from OU7 and exposure pathways to receptor populations identified in Section 3.0.

An exposure pathway is a specific environmental route by which an individual may potentially be exposed to chemical constituents present on, or originating from, a site. An exposure pathway includes five necessary elements:

- Source of chemicals
- Mechanism of chemical release
- Environmental transport medium
- Exposure point
- Human intake route

All five elements must be present for an exposure pathway to be complete. An incomplete pathway means that no human exposure can occur. Only potentially complete and relevant pathways for the Phase I investigation will be addressed in the HHRA for OU7. An exposure pathway is considered to be potentially complete and relevant if there are potential chemical release and transport mechanisms and receptors for that pathway.

4.1 Chemical Release Sources and Transport Media

The identified site sources at OU7 are the Present Landfill and contaminated soil. The Phase I HHRA will evaluate landfill solid waste and contaminated soil at these areas as the primary sources of chemical release. A description of activities conducted at OU7 is provided in Section 2.1. Environmental media that may transport chemicals of concern from OU7 to exposure points are described below in the conceptual site model.

4.2 Potentially Exposed Receptor Populations

Potentially exposed receptor populations selected for quantitative assessment in the baseline HHRA were characterized in Section 3.0. The following receptors were selected:

- Current onsite worker
- Current offsite resident
- Hypothetical future onsite worker
- Hypothetical future onsite ecological researcher
- Hypothetical future onsite resident

The current offsite resident is evaluated under current land use conditions. The future land use scenarios assume no action takes place at OU7 and estimate exposure for future receptor populations under this condition.

4.3 Exposure Points

An exposure point is a specific location where human receptors may come in contact with site-related chemicals. Exposure points are selected so that reasonable maximum exposures will be quantitatively evaluated. Evaluation of receptor risks at these exposure points will bound the risks for receptors at other exposure points not selected for quantitative evaluation. The following exposure points were selected based on reasonable maximum estimates of risk. The exposure point locations are shown in Figure 3-7.

Current Scenario

- Occupational Receptor. Present landfill worker within the boundary of OU7.

- Residential receptor. Nearest residence to RFP (located at the southeastern corner of the RFP property boundary) and nearest residence in the predominant wind direction.

Future Scenario

- Occupational receptor. Hypothetical onsite worker within the boundary of OU7.
- Ecological researcher. Hypothetical onsite ecological researcher within the boundary of OU7.

- Residential receptor. Hypothetical onsite resident within the boundary of OU7.

4.4 Human Uptake Mechanisms

A human uptake mechanism is the route by which a chemical is absorbed by the receptor. The four basic human uptake mechanisms are dermal absorption, inhalation, ingestion, and, if radionuclides are present, external exposures. Exposure pathways that potentially lead to these mechanisms include inhalation of volatile organic compounds (VOCs) and airborne particulates, ingestion of soil, and dermal contact with soil or surface water. These uptake mechanisms are described further in Section 5.0.

Dermal absorption of metals from contact with soil is not considered by EPA to be a significant uptake route. The Preliminary Risk Assessment for Leadville, Colorado, prepared by EPA Region VIII, states:

> Metals bind strongly to soil greatly reducing their bioavailability. Through complex processes, most metals form strong, stable bonds with other soil constituents that reduce the available concentration of a dissolved metal. In addition, due to polarity and solubility, metals are not absorbed well across the skin. Therefore, relative to other exposure routes, dermal absorption is expected to be inconsequential (EPA 1989b). Additionally, according to recent EPA guidance (EPA 1992b), dermal exposures to contaminants in soils are significant relative to oral or inhalation exposures, only when the skin surface area available for contact is significant, and only for "chemicals which have a percent absorbed exceeding about 10%." This same guidance says that the dermal absorption percentage for metal (based on cadmium) is on the order of 0.1% to 1.%, thus showing that the magnitude of exposure to metals at the site via dermal absorption will not be significant relative to other routes of exposure. Therefore, dermal exposure to metals will not be evaluated in this assessment.

For radionuclides, EPA guidance states that "dermal uptake is generally not an important route of uptake for radionuclides, which have small dermal permeability constants" (EPA 1989b). Dermal contact with soil will be assessed quantitatively only if results of OU7 Phase I sampling programs demonstrate the presence of organic chemicals of concern in surface soils at concentrations exceeding background levels.

4.5 Conceptual Site Model

Information concerning waste sources, waste constituent release and transport mechanisms, and locations of potentially exposed receptors is used in this section to develop a conceptual understanding of the site in terms of potential human exposure pathways. Figure 4-1 shows a CSM of potential human exposure pathways for OU7. As noted in Section 1.2, the nature and extent of contamination in surface water and groundwater will not be investigated until the Phase II RFI/RI. Therefore, this technical memorandum addresses only direct and upward exposure pathways. Potential downward pathways are shown in the CSM in order to put the current scope of analysis in context with the overall remediation.

The CSM is a schematic representation of the chemical source areas, chemical release mechanisms, environmental transport media, potential human intake routes, and potential human receptors. The purpose of the CSM is to provide a framework for problem definition, identify exposure pathways that may result in human health risks, indicate data gaps, and aid in identifying appropriate remediation measures. Chemical release mechanisms, environmental transport media, and potential human intake routes to the contaminated site soil were identified for each potentially exposed receptor and are discussed below in Section 4.5.1.

As shown in the CSM, professional judgement was used to determine whether potentially complete exposure pathways will result in significant or insignificant levels of exposure. Potentially complete and relatively significant exposure pathways are designated on the CSM by an "S." Potentially complete and relatively insignificant exposure pathways are designated by an "I." Both potentially complete and relatively significant exposure pathways and relatively insignificant exposure pathways will be quantitatively addressed in the risk assessment. Quantitatively addressing potentially complete and relatively insignificant exposure pathways will provide for risk estimates that do not underestimate actual risks.

4.5.1 Sitewide Incomplete or Negligible Exposure Pathways

As indicated on the CSM, the following OU7 exposure pathway has been determined to be negligible for all receptors. This pathway will not be quantitatively addressed in the risk assessment.

- Groundshine from wind suspension and subsequent deposition: External irradiation exposures resulting from deposition of radionuclides via airborne particulates are expected to be negligible. Although water sampling programs have shown radioactive contamination, soil sampling, while not considered conclusive, has not detected radioactive material in the soil above sitewide background levels. Since 1973, radiation monitoring has been performed with a Field Instrument for Detection of Low Energy Radiation (FIDLER) prior to covering and the addition of the final top layer of soil. For these reasons, it is not expected that concentrations of radioactive material at or under the surface of the landfill are sufficient to cause significant external exposures from fugitive dust. Additionally, because of the effective dilution of material during fugitive dust transport offsite, exposures from the radionuclides deposited on surface soils are expected to be negligible.

No other sitewide negligible or incomplete exposure pathways are believed to exist for the site. Specific exposure pathways that will be evaluated for each exposure scenario are described below by receptor.

4.5.2 Potentially Complete Exposure Pathways

4.5.2.1 Current Onsite Worker

For the purposes of this evaluation, it is assumed that the population of current onsite workers consists of those individuals involved with operations of the active landfill. As indicated on the CSM, it has been determined that these current onsite workers could be exposed to site-related compounds via inhalation of either volatilized gasses from the landfill or wind-suspended particulate matter, as well as via direct contact with site soils. Therefore, exposures incurred via inhalation or direct contact are included in this evaluation.

Owing to the close proximity of the landfill workers with the landfill, it is anticipated that this population would be the most likely to incur exposure to VOCs emitted from the landfill. However, because these workers are not continuously working on the landfill site, and because exposures would occur in an outdoor environment where emissions of VOCs would become quickly diluted, it is expected that these exposures would be relatively insignificant.

Because of the nature of the work on the landfill, these onsite workers would be expected to incur exposures to airborne particulates. However, the limited daily duration of exposure of workers on the landfill, the low likelihood that they will spend significant amounts of time downwind from the landfill, and the fact that current onsite workers are operating under an occupational health and safety plan suggest that exposure to airborne particulates would also be relatively insignificant. To ensure that final estimates of exposure (and the associated risk) are health-conservative, potential exposure to VOCs and airborne particulates will be included in the evaluation of exposures potentially incurred by the current onsite workers.

Because the current onsite workers are active on the landfill, it is assumed that these individuals will come into direct contact with the site soils and could therefore, incur incidental ingestion exposures as well as direct dermal contact with soils and groundshine. As with inhalation exposures, the magnitude of these exposures should be mitigated since the landfill workers are specifically trained and working under an occupational health and safety plan. Therefore, as indicated on the CSM, these exposures are assumed to be relatively insignificant, but are included in the assessment in order to be comprehensive and health-conservative.

External irradiation from decay of radioactive materials in contaminated surface soils (groundshine) is also a potentially complete but insignificant exposure pathway. Although water sampling results indicate the presence of radioactive material in the landfill, soil sampling data, while not conclusive, have not detected radioactive material in the soil above sitewide background levels. Since 1973, radiation monitoring has been performed with a

FIDLER prior to covering and prior to the addition of the final top layer of soil. For these reasons, it is not expected that concentrations of radioactive material exist at or under the surface of the landfill at levels sufficient to cause significant external exposures. However, external radiation from direct contact with the soil will be evaluated as a potentially complete but relatively insignificant exposure pathway for the current onsite worker.

Several exposure pathways are considered to be incomplete for the current onsite worker. First, it is assumed that there will be no exposures to indoor air because there are currently no structures on the site. Second, it is assumed that secondary exposure to soils following wind deposition of particulates is negligible relative to direct exposures to site soils. Finally, all exposures incurred via ingestion of plants (particulate deposition and plant uptake) are incomplete exposure pathways because no edible crops are grown on the site for workers to ingest.

In summary, potentially complete human exposure pathways for the current onsite workers are:

- Inhalation of outdoor VOCs and airborne particulates
- Incidental soil ingestion from direct contact
- Direct dermal contact with site soils
- Groundshine (direct contact)

4.5.2.2 Current Offsite Resident

As the CSM for the current offsite resident indicates, airborne dispersal following volatilization or suspension of particulates is the primary transport mechanism from contaminated site soils to the current offsite resident. Therefore, exposures associated with exposure of the current offsite residents to site-related compounds in the air or particulates deposited onto soils and vegetation are included in the evaluation.

Direct ingestion and dermal contact with site soils and onsite external irradiation from radioactive decay of radionuclides on site soils are also primary release mechanisms but are incomplete exposure pathways for offsite receptors because site access is restricted.

Therefore, current offsite residents could not come into direct contact or even close proximity to contaminated soils on site. Similarly, exposure to site contaminants from consumption of vegetables that have taken up compounds directly from site soils is an incomplete pathway because offsite residents would not have access to vegetation grown onsite.

VOCs emitted from the landfill could be transported to an offsite receptor living downwind from the site. It is expected that these exposures will be relatively insignificant, owing to the effect of dilution on the air concentrations of VOCs. However, to ensure that final estimates of risk are health-conservative, potential exposures to VOCs will be included in the evaluation of exposures potentially incurred by the current offsite resident. Indoor VOC exposure will not be assessed because the source of VOCs is not located underneath an offsite residence.

Chemicals bound to soils transported via wind as particulates represent potential inhalation, oral, and dermal exposure pathways. It is also expected that these exposures will be relatively insignificant because of the effect of dilution on particulate matter air concentrations. Current offsite residents may be directly exposed to airborne particulates via inhalation; consequently, this is a potentially complete but insignificant pathway. Homegrown garden vegetables subject to deposition of airborne particulates from the sites also represent a potentially complete, although insignificant, ingestion pathway. Similarly, contaminated (from deposition of airborne particulates) soil represents potentially complete but insignificant oral and dermal exposure pathways for this receptor.

Plant uptake of contaminants deposited as windblown particulates on soil may potentially occur. However, this uptake is considered insignificant for the following reasons:

- As mentioned in Section 4.4, metals and many organic compounds bind tightly to soil, thus greatly reducing their bioavailability to plants (EPA 1991a).

- Chemical concentrations from particulates deposited on residential soil will be significantly diluted by tilling. Since tilling will mix the thin layer of surface soils that are impacted by site-related contaminants in with several inches of soils that are not impacted.

- Transfer from soil to plant will again dilute any uptake into the plant.

- Soil particles will be largely stripped of VOCs during wind transport.

For these reasons, chemical concentrations in garden vegetables that result from surface deposition of contaminated particulates are expected to be greater than those from uptake by vegetables from the soil. Therefore, current residential intake of vegetables will only be evaluated for surface deposition of particulates on plants.

In summary, potentially complete human exposure pathways for the current offsite resident include:

- Inhalation of outdoor VOCs and airborne particulates
- Soil ingestion following airborne deposition of particulates on residential soil
- Dermal contact with soil, following airborne deposition of particulates
- Ingestion of vegetables following surface deposition of particulates

4.5.2.3 Hypothetical Future Onsite Worker

In order to characterize exposures that could potentially occur should the site be developed into office buildings, this assessment includes an evaluation of a hypothetical future onsite office worker who is exposed indoors during the work day and outdoors during a lunch break.

As the CSM for the future onsite worker indicates, volatilization, wind suspension, and direct contact are the primary chemical release mechanisms from the site to this exposed population.

Chemicals that volatilize from site soils represent a potentially complete inhalation pathway for the future onsite worker. It is possible for VOCs to accumulate indoors to a higher level than in outdoor air because of limited dilution in the enclosed environment. For this reason, the inhalation pathway for VOCs is considered insignificant outdoors but potentially significant indoors.

Chemicals bound to soil particles suspended and transported by the wind represent negligible oral and dermal exposure pathways; however, future onsite workers may be exposed to airborne particulate matter via inhalation. Inhalation is considered to be a potentially complete and significant pathway due to proximity to the source. Direct contact with contaminated soil represents potentially complete oral (significant) and dermal (relatively insignificant) exposure pathways. Because of the dilution effect during wind transport of contaminated soil, the oral and dermal pathways from wind suspension are negligible compared to direct oral and dermal exposures to the soil by onsite workers. It is assumed that site workers would not consume vegetation grown onsite. Therefore, wind deposition and plant uptake of site-related compounds are considered incomplete for the hypothetical future onsite workers.

External irradiation from decay of radioactive materials in contaminated surface soils (groundshine) is also a potentially complete but insignificant exposure pathway. As described in Section 4.5.2.1, available data from water sampling and a FIDLER monitoring indicate that concentrations of radioactive material do not exist at or under the surface of the landfill at levels sufficient to cause significant external exposures. However, external radiation from direct contact with the soil will be analyzed as a potentially complete but relatively insignificant human exposure pathway for the hypothetical future onsite worker.

Exposure to radioactive materials via ingestion, oral, or dermal uptake routes is accounted for in the other potentially complete exposure pathways described for this receptor.

In summary, potentially complete, non-negligible, human exposure pathways for the future onsite worker are:

- Inhalation of VOCs in indoor and outdoor air
- Inhalation of airborne particulates
- Incidental soil ingestion

- Direct dermal contact with soil
- Groundshine (direct contact)

4.5.2.4 Hypothetical Future Onsite Ecological Researcher

As the CSM indicates, it has been determined that volatilization, wind suspension, and direct contact are the primary release mechanisms that are part of complete exposure pathways from site soils to a future onsite ecological researcher. External radiation exposure from contaminated soils is also a potentially complete pathway.

Except for inhalation of impacted indoor air, all of these primary release mechanisms have associated exposure routes that are potentially complete for the future ecological researcher. Chemicals that volatilize from the site may be released to indoor air and outdoor air. Inhalation of VOCs in outdoor air is considered to be a relatively insignificant pathway. Inhalation of indoor air is an incomplete exposure pathway for an ecological researcher because the researchers will spend their time outdoors while on site.

Chemicals bound to soils that are released via wind as particulate matter represent potential inhalation, oral, and dermal exposure pathway following deposition. Of these, exposures to airborne particulate matter via inhalation is potentially significant because the receptor is located so near the source area. The impact of incidental ingestion of contaminated soil and dermal absorption of chemicals in soil following wind deposition are considered to be negligible in comparison to the potential exposures incurred via direct ingestion and dermal exposure to site soils. For direct contact with site soils, incidental ingestion is expected to be potentially significant. Relative to these ingestion exposures, dermal exposure is expected to be insignificant.

It is assumed that an ecological researcher working at RFP would not consume vegetation grown on the site. Therefore, wind deposition of particulates onto plants and subsequent uptake of these contaminants are considered to be incomplete exposure pathways for the researcher scenario.

External irradiation from decay of radioactive materials in contaminated site surface soils (groundshine) is also a potentially complete but insignificant exposure pathway. Although water sampling data indicate the presence of radioactive material in the landfill, soil sampling data, while not conclusive, have not detected radioactive material in the soil above sitewide background levels. Since 1973, radiation monitoring has been performed with a FIDLER prior to covering and prior to the addition of the final top layer of soil. For these reasons, it is not expected that concentrations of radioactive material exist at or under the surface of the landfill sufficient to cause significant external exposures. However, external radiation from direct contact with the soil will be analyzed as a potentially complete but relatively insignificant human exposure pathway.

Exposure to radioactive chemicals via ingestion, oral, or dermal uptake routes other than external irradiation is accounted for in the other potentially complete exposure pathways described for this receptor.

In summary, potentially complete, non-negligible, exposure pathways for chemicals released from contaminated site soils for the future ecological researcher are:

- Inhalation of outdoor VOCs and airborne particulates
- Incidental soil ingestion
- Direct dermal contact with soil
- Groundshine (direct contact)

4.5.2.5 Hypothetical Future Onsite Resident

As the CSM indicates, volatilization, wind suspension, uptake of compounds into plants, and direct contact are all chemical release mechanisms that are part of complete exposure pathways from site soils to a hypothetical future onsite resident.

Chemicals that volatilized from the site may be released to indoor air and outdoor air. It is possible for VOCs to accumulate indoors to a greater extent than in outdoor air because of the limited dilution in the enclosed environment. For this reason, the inhalation pathway for VOCs is considered to be insignificant outdoors, but potentially significant for indoor exposures for an onsite resident.

Chemicals bound to soil particles suspended and transported by wind as negligible oral and dermal exposure pathways, but inhalation of these particulates presents a potentially significant route of exposure to site-related compounds. Because this receptor is located directly on the site, the oral and dermal exposures contributed from wind deposition of particulates will be negligible compared to the oral and dermal exposures that are anticipated to result from direct contact with site soils. Hence, incidental soil ingestion and dermal exposure from wind-deposited soils will not be included in this assessment. Airborne deposition of soil-bound contaminants onto the surface of vegetables grown on the site could, however, be potentially significant and is therefore included in the evaluation of potential future onsite residential exposures. For direct contact with site soils, the exposures resulting from incidental ingestion are expected to be potentially significant. Relative to these ingestion exposures, dermal exposure will be insignificant because of the effectiveness of skin as a barrier to contaminant absorption and the impact of the matrix effect on the release of contaminants.

Hypothetical future onsite residents could maintain home gardens. Vegetables grown in these gardens could accumulate site-related contaminants as a result of both uptake from site soils and deposition onto exposed surfaces. Because the hypothetical future resident is assumed to live directly on the site, vegetables grown by these residents could be in direct contact with impacted soils. This maximizes the possibility that human consumption of home grown vegetables would result in potentially significant exposure to site-related chemicals. This assessment assumes that site soils are not tilled prior to planting, so no dilution of site contaminants would occur.

It has been demonstrated that resuspension and deposition of particulates onto the surface of vegetables can dominate contaminant concentrations in plants (Whicker 1990). Although root uptake is comparatively unimportant, at least for long-lived contaminants in soils, evaluation of potential human exposures to site-related chemicals from consumption of plants will include possible root uptake to ensure that final estimates of exposure are conservative.

External irradiation from decay of radioactive materials in contaminated site surface soils (groundshine) is also a potentially complete but insignificant exposure pathway. Although water quality data indicate the presence of radioactive material in the landfill, soil data, while not conclusive, have not shown radioactive material in the soil above sitewide background levels. Since 1973, radiation monitoring has been performed with a FIDLER prior to covering and prior to the addition of the final top layer of soil. For these reasons, it is not expected that concentrations of radioactive material exist at or under the surface of the landfill sufficient to cause significant external exposures. However, external radiation from direct contact with the soil will be analyzed as a potentially complete but relatively insignificant human exposure pathway.

Exposure to radioactive chemicals via ingestion, oral, or dermal uptake routes other than external irradiation is accounted for in the other potentially complete exposure pathways described for this receptor.

In summary, potentially complete, non-negligible, human exposure pathways for chemicals released from contaminated site soils for the hypothetical future onsite resident are:

- Inhalation of VOCs in indoor and outdoor air
- Inhalation of airborne particulates
- Ingestion of homegrown vegetables (surface deposition of particulates and root uptake of site-related chemicals)
- Incidental soil ingestion
- Direct dermal contact with soil
- Groundshine (direct contact)

A summary of potentially complete exposure pathways that will be quantitatively evaluated in the baseline human health risk assessment is provided in Table 4-1.

Table 4-1
Rocky Flats Plant OU7
Potentially Complete Exposure Pathways to be Quantitatively Evaluated

Potentially Exposed Receptor	Scenario	Potentially Complete Exposure Pathways
Onsite worker	Current	Inhalation of airborne particulates Inhalation of outdoor VOCs Incidental soil ingestion Direct dermal contact with surface soil Groundshine (direct contact)
Offsite resident	Current	Inhalation of airborne particulates Inhalation of outdoor VOCs Soil ingestion (following deposition of particulates) Dermal contact with surface soil (following deposition of particulates) Ingestion of vegetables (following deposition of particulates)
Hypothetical onsite worker	Future	Inhalation of indoor and outdoor VOCs Inhalation of airborne particulates Incidental soil ingestion Dermal contact with soil Groundshine (direct contact)
Hypothetical onsite ecological researcher	Future	Inhalation of particulates Inhalation of outdoor VOCs Incidental soil ingestion Direct dermal contact with surface soil Groundshine (direct contact)
Hypothetical onsite resident	Future	Inhalation of airborne particulates Inhalation of indoor and outdoor VOCs Ingestion of vegetables (surface deposition of particulates and root uptake) Incidental soil ingestion Direct dermal contact with surface soil Groundshine (direct contact)

5.0 ESTIMATING CHEMICAL INTAKES

This section presents reasonable maximum intake parameters for each of the receptors and exposure pathways identified in previous sections. Specific chemical intakes are not presented in this memorandum since they are dependent on pending site characterization to provide exposure point concentrations.

Using the exposure point concentrations of chemicals in soils and air, it is possible to estimate the potential human intake of those chemicals via each exposure pathway. Intakes are expressed in terms of chemical (mg)/body weight (kg)/day. Intakes are calculated following guidance in *Risk Assessment Guidance for Superfund* (EPA 1989a) and *Exposure Factors Handbook* (EPA 1989b), other EPA guidance documents as appropriate, and professional judgment regarding likely site-specific exposure conditions. Intakes are estimated using reasonable estimates of body weight, inhalation volume, ingestion rates, soil or food matrix effects, and frequency and duration of exposure.

Intakes are estimated for reasonable maximum exposure (RME) conditions. The RME is estimated by selecting values for exposure variables so that the combination of all variables results in the maximum exposure that can reasonably be expected to occur at the site.

The general equation for calculating intake in terms of mg/kg/day is:

$$\text{Intake} = \frac{\text{chemical conc.} * \text{contact rate} * \text{exposure freq.} * \text{exposure duration} * \text{absorption fraction}}{\text{body weight} * \text{averaging time}}$$

$$\text{mg/kg/day} = \frac{\text{mg/vol} * \text{vol/day} * \text{day/year} * \text{year} * \%}{\text{kg} * \text{day}}$$

The variable "averaging time" is expressed in days to calculate daily intake. For noncarcinogenic chemicals, intakes are calculated by averaging over the period of exposure to yield an average daily intake. For carcinogens, intakes are calculated by averaging the total cumulative dose over a lifetime, yielding "lifetime average daily intake." Different averaging times are used for carcinogens and noncarcinogens because it is thought that their effects occur by different mechanisms of action. The approach for carcinogens is based on the current scientific opinion that a high dose received over a short period of time is equivalent to a corresponding low dose spread over a lifetime. Therefore, for whatever exposure duration, the intake of a carcinogen is averaged over a 70-year lifetime (EPA 1989a). Intake of noncarcinogens is averaged over the period of exposure since the average concentration of a noncarcinogen is compared with the threshold dose for an effect.

Omitting chemical concentrations from the intake equation yields an "intake factor" that is constant for each exposure pathway and receptor. The intake factor can then be multiplied by the concentration of each chemical to obtain the pathway-specific intake of that chemical. Intake factors are calculated separately for each potentially exposed receptor and exposure pathway that was identified in Section 4.5. Because contact rates (except for soil ingestion) are approximately proportional to body weight, child residential intakes are not estimated separately for any exposure pathway except soil ingestion, for which children are assumed to have higher daily intake rates. The assumptions used in deriving intake factors are discussed below.

5.1 Intake Factor Assumptions

Several exposure parameters, such as exposure duration, body weight, and averaging times, have general application in all intake estimations, regardless of pathway. These general assumptions, as well as pathway-specific assumptions, are detailed in the section below. The term "occupational exposures" includes exposures to both the future onsite worker and the hypothetical future ecological researcher.

5.1.1 General Exposure Assumptions

- For all exposure scenarios, the RME exposure frequency has been estimated to be 3 days/week for 50 weeks/year for the current onsite worker, 7 days/ week for 50 weeks for the current and future offsite resident (EPA 1991b), 5 days/week for 50 weeks for the hypothetical future onsite worker (EPA 1991b), and 5 days/week for a 16 week field season for the ecological researcher. Where appropriate, exposure frequencies are then adjusted to account for snowfall in the area, assuming that accumulation of snow on the ground will obscure exposures. Based on information from the Assistant State Climatologist for Colorado (Doesken 1992), the 30-year average precipitation record indicates that there is at least 1 inch of snow cover on the ground for 60 days each year.

- Residential RME exposure duration is assumed to be 30 years (EPA 1991b).

- The RME exposure duration for the current landfill worker is assumed to be 5 years, based on the assumption that the landfill will be closed within this period.

- Occupational RME exposure durations for hypothetical future onsite workers are assumed to be 25 years. This reasonable maximum duration is the 95th percentile duration of work at the same location (EPA 1991b).

- Averaging time for exposure to non-carcinogenic compounds is the product of the exposure duration and the number of days in a year (365).

- Averaging time for carcinogenic effects is 70 years (25,550 days) in the reasonable maximum case.

- The average adult body weight is assumed to be 70 kg (EPA 1989b).

5.1.2 Inhalation Assumptions

Uptake of chemicals through inhalation is a function of the volume of air inhaled per day, the exposure frequency and duration, and pulmonary deposition (for particulate inhalation). Intake factors for exposure via particulate or VOC inhalation were estimated for appropriate receptors. The following assumptions will be used to estimate exposure to chemicals of concern through this route.

- The RME respiratory volume of air for all residential receptors is assumed to be 0.83 m^3/hr (20 m^3/day). This is a suggested average value for continuous (i.e., 24-hour) exposures. Separate inhalation rates for indoor and outdoor workers of 0.63 and 1.4 m^3/hr, respectively, were incorporated for the appropriate occupational receptors (EPA 1989b).

- Current and future onsite occupational receptors are assumed to breathe onsite air 4 or 8 hours/day, respectively in the RME case.

- Current and future residential receptors are assumed to be exposed for 24 hours/day in the RME case. This exposure frequency incorporates the health-conservative assumption that residential receptors are at home all day.

- Twenty-five percent of inhaled particles are deposited in the lung; it is assumed that all chemicals in that fraction are absorbed (MRI 1985).

- It is assumed that inhaled VOCs are retained in the lung and absorbed on a chemical-specific basis. Unless the toxicity factors used are based on inhalation exposure studies (e.g., RFC available) values on lung retention available from the literature will be used to determine the chemical-specific absorption value.

5.1.3 Soil Ingestion Assumptions

Uptake of chemicals via incidental ingestion of soil and dust is a function of the ingestion rate, the fraction of ingested soil or dust that is contaminated, the frequency and duration of exposure, and the bioavailability of the chemical adhered to the particulates ingested.

The calculation of an RME 30-year residential exposure to soil will be divided into two parts. First, a six-year exposure duration is evaluated for young children, thus accounting for the period of highest soil ingestion and lowest bodyweight. Second, a 24-year exposure duration is assessed for older children and adults using a lower soil ingestion rate. By time-averaging the child residential soil ingestion exposures with the exposures calculated for the adult, a child residential exposure from soil ingestion is taken into account.

Intake factors for exposure via soil ingestion were calculated for current landfill workers, an adult resident, a child resident, a future onsite ecological researcher, a hypothetical future onsite worker, and a hypothetical future onsite resident. The following assumptions will be used in estimating intake through this route.

- Occupational receptors are assumed to ingest 50 mg/day of soil in the RME case (EPA 1991b).

- The calculation of a 30-year residential exposure to soil is time-averaged by assessing a six-year childhood exposure duration followed by a 24-year adult exposure duration. The six-year exposure duration is evaluated for young children, and this accounts for the period of highest soil ingestion (200 mg/day) and lowest body weight (15 kg) (EPA 1991b). The 24-year exposure duration is assessed for older children and adults and accounts for the period of lower soil ingestion (100 mg/day) and an adult body weight (70 kg) (EPA 1991b).

- The fraction ingested (FI) from the contaminated source is assumed to be 0.5 for current landfill workers, 0.125 for the future onsite worker, 0.006 for the hypothetical future onsite ecological researcher, and 0.5 for the current and future residential receptor. The FI of 0.5 for current onsite workers assumes that 4 hours of each day are spent on the landfill. The FI for the future onsite worker is based on 1 hour of exposure to contaminated soil per 8-hour workday. This assumes that the onsite worker spends his/her entire lunch hour outside. The future onsite ecological researcher is assumed to spend time at OU7 in relative proportion of the area of OU7 to the area of the total buffer zone during a career of research at RFP. Residential receptors are assumed to be exposed to contaminated soils for 50 percent of the time that they are present at their homes.

- The matrix effect of soil on bioavailability of ingested contaminants can be significant and will be evaluated for all soil ingestion exposures on a chemical-specific basis. The matrix effect describes the reduced availability of site-related chemicals due to adsorption of chemicals to soil compared to the same chemical dose administered in solution. Therefore, the soil matrix has the effect of reducing chemical intake.

5.1.4 Homegrown Produce Ingestion Assumptions

It is assumed that contamination of homegrown produce may occur by surface deposition of particulates or by root uptake of chemicals into the plant. Human exposure to chemicals via ingestion of homegrown vegetables is a function of the ingestion rate, the fraction of contaminated homegrown produce ingested, the frequency and duration of exposure, and the amount and bioavailability of the chemical adhered to, or taken up into, the produce ingested. An intake factor for exposure via vegetable ingestion was calculated for current and hypothetical future residential receptors. Current or future onsite workers and ecological researchers are not expected to ingest produce from the site. The following assumptions will be used in estimating intake through this route.

- Current and hypothetical future residential receptors are assumed to ingest an annual average of 26,667 mg/day of site-impacted vegetables in the RME case. This RME figure is based on the "typical" consumption value of vegetables (200,000 mg/day), assuming a "reasonable worst case" proportion of 40 percent being homegrown (EPA 1991b) and a 4-month harvesting season.

  Homegrown vegetables are assumed to be potentially contaminated by surface deposition of airborne particulates from OU7 soils at both offsite and onsite locations. Modeled soil loading rates will be applied to reasonable maximum estimates of vegetable surface areas, weights, and human consumption rates to estimate chemical intake from this potential exposure pathway. For hypothetical future onsite residential exposure, it is also assumed that plants may contain site-related chemicals following root uptake. Anticipated chemical concentrations in plants will be calculated using values available in the literature.

- The matrix effect of produce on bioavailability of ingested contaminants will be evaluated on a chemical-specific basis, and is assumed to be the same as the values used for soil ingestion where contaminants are present as a result of surface deposition.

Reductions in chemical concentrations due to washing, cooking, or peeling of produce are not accounted for although they may have a significant effect on concentrations. Thus, these calculations yield a health-conservative estimate of exposure.

5.1.5 Dermal Contact with Soil

Uptake of chemicals of concern through dermal contact with surface soil is a function of body surface area, absorbed fraction, an adherence factor that describes how much soil adheres to skin, the fraction of soil contacted that is from a contaminated source, and exposure frequency and duration. As described in the above discussion of Uptake Mechanisms (Section 4.4), dermal uptake of metals is expected to be negligible and is not addressed in this assessment. Dermal contact with surface soil will only be evaluated if sampling demonstrates the presence of organic compounds. The following assumptions will be used to estimate exposure to chemicals of concern through dermal contact with soil for all receptors.

- The RME exposed body surface area for all receptors is assumed to be 2,190 cm^2/day. The reasonable maximum surface area is assumed to be equivalent to face, forearms, and hands (or 15 percent of total body surface area) (EPA 1989b).

- The absorbed fraction is the estimated fraction of organic compounds (if available) adhered to soil particles that partitions to and is absorbed through skin. This fraction is chemical-specific. Percent absorbed depends upon soil loading, organic carbon content of soil, contaminant concentration, duration of exposure, animal species used in the experiment, and whether the experiment is conducted in vitro or in vivo. The absorbed fraction will be determined on a chemical-specific basis using data available in the scientific literature.

- The soil adherence factor used is 0.6 mg/cm^2 in the RME case. This value represents the midpoint in the range of currently recommended values for soil adherence (EPA 1992b).

- The fraction contacted (FC) from the contaminated medium is assumed to be 0.5, 0.125, 0.006, and 0.5 in the RME case for the current onsite worker, future onsite worker, the future onsite ecological researcher, and the current and future residential receptor, respectively. The FC for the current onsite worker is based on an assumed 4 hours of exposure to site soils per 8-hour work day. The FC for the future onsite worker is based on 1 hour of exposure to contaminated soil per 8-hour workday. The future onsite ecological researcher is assumed to conduct field research at OU7 in relative proportion of the area of OU7 to the area of the total buffer zone at RFP. Residential receptors are assumed to be exposed to contaminated soil for 50 percent of the time that they are at their residence. This fraction assumes that 16 hours per day are spent at home and 8 hours per day are spent at away from home at work or school. Of the 16 hours spent at home, it is assumed that 8 hours are spent indoors and the remaining 8 hours are spent outdoors in activities that may potentially involve dermal contact with contaminated soil.

5.1.6 Internal Exposure to Radionuclides

Intake of radionuclides by ingestion, inhalation, or absorption, which leads to incorporating the radionuclides into the tissues and organs of the body will result in a radiation dose to those organs as well as to surrounding tissues. This intake is a function of the radionuclide concentration and the frequency and duration of exposure to the radioactive material. Calculation of intake rates for radionuclides from the environment into the body can be made in the same manner as other nonradioactive chemicals except neither averaging time nor body weight are used as parameters. The resulting calculation is an estimate of the radionuclide intake, expressed in units of radioactivity (e.g., Bq or Ci) (EPA 1989a).

The radiation dose from the intake of radioactive material is a function of the type of radiation emitted by the radionuclide. The dose equivalent was developed to normalize the unequal biological effects from the different types of radiation. Because radiation doses from systemically incorporated radionuclides may continue long after the intake of the nuclide has ceased, doses to specific tissues and organs from internal radionuclides are typically reported in terms of the committed dose equivalent. The committed dose equivalent to specific organs as a result of intake of the radioactive material is estimated by multiplying the intake of each radionuclide by the appropriate dose conversion factor (DCF). The committed dose equivalents for each radionuclide are then summed to obtain a total committed dose equivalent. Internal exposures to radionuclides will be calculated using this approach to compare exposures with applicable standards given in terms of committed dose equivalents.

5.1.7 External Irradiation

To estimate risks from exposure to radiation from sources outside the body, average radionuclide concentrations in the landfill material (Bq/gm or pCi/gm), whether directly measured or estimated by modeling, are multiplied by the appropriate slope factor for radionuclide carcinogenicity from the *Health Effects Assessment Summary Tables* (EPA 1992 c) and the exposure duration (years). The slope factor for radionuclide carcinogenicity is based on an exposure time of 24 hours per day and an exposure frequency of 365 days per year.

Risk from external irradiation may be estimated by multiplying the slope factor times the radionuclide concentration and an exposure factor. The exposure factor is analogous to an intake factor and is calculated as:

$$\text{Exposure factor} = \frac{\text{Exposure time x exposure frequency x exposure duration}}{\text{Baseline exposure time x baseline exposure frequency}}$$

Dividing of RME exposure times and exposure frequencies by the baseline values of 24 hours per day and 365 days per year accommodates exposure scenarios that are not continuous.

5.2 Intake Factor Calculations

The assumptions and values described above will be used to calculate intake or exposure factors for each exposure pathway and receptor. Parameters to be used for calculations of intake and exposure factors are shown in Tables 5-1 through 5-21. Exposure point concentrations will be used with these parameters to obtain pathway-specific intakes or exposures.

Table 5-1 Soil Ingestion, Current Onsite Worker

$$\text{Intake Factor} = \frac{IR \times FI \times ME \times EF \times ED \times CF}{BW \times AT}$$

		Parameter	RME
IR	=	Ingestion rate (mg/day)[a]	50
FI	=	Fraction ingested from contaminated source[b]	0.5
ME	=	Matrix effect[c]	chemical-specific
EF	=	Exposure frequency (days/year)[d]	124
ED	=	Exposure duration (years)[e]	5
CF	=	Conversion factor (kg/mg)	10^{-6}
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	1,825
		Carcinogenic	25,550

a EPA (1991b)

b Based on 4-hours of exposure to site soils per 8-hour work day.

c The matrix effect describes the reduced availability due to adsorption of chemicals to soil compared to the same dose administered in solution. Therefore, the soil matrix has the effect of reducing the dose of a compound (Poiger and Schlatter 1980). These values are chemical-specific.

d EPA 1991b, adjusted for snowcover. Assumes exposure at the landfill 3 days per week, 50 weeks per year, but accounts for 60 days/year of snowcover, 3/7 of which are assumed to occur during the days where landfill workers are onsite.

e Assumes landfill to be closed within 5 years.

Table 5-2 Inhalation of Particulates, Current Onsite Worker

$$\text{Intake Factor} = \frac{IR \times ET \times EF \times ED \times DF}{BW \times AT}$$

Parameter			RME
IR	=	Inhalation rate (m^3/hr)[a]	1.4
ET	=	Exposure time (hours/day)[b]	4
EF	=	Exposure frequency (days/year)[c]	124
ED	=	Exposure duration (years)[d]	5
DF	=	Deposition factor[e]	0.25
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	1,825
		Carcinogenic	25,550

[a] Recommended average inhalation rate for outdoor workers (EPA 1989b).

[b] The ET is based on 4 hours of exposure at the site per day.

[c] Assumes exposure at the landfills 3 days per week, 50 weeks per year, and accounts for 60 days/yr of snowcover, 3/7 of which are assumed to occur during days when landfill workers are onsite.

[d] Assumes landfill closure within 5 years.

[e] Twenty-five percent of inhaled particles are deposited and remain in the lung; it is assumed that all of the chemicals in that fraction are absorbed (MRI 1985).

Table 5-3 Inhalation of VOCs, Current Onsite Worker

$$\text{Intake Factor} = \frac{IR \times ET \times EF \times ED \times AF}{BW \times AT}$$

Parameter			RME
IR	=	Inhalation rate (m^3/hr)[a]	1.4
ET	=	Exposure time (hours/day)[b]	4
EF	=	Exposure frequency (days/year)[c]	124
ED	=	Exposure duration (years)[d]	5
AF	=	Absorption Fraction	chemical-specific
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	1,825
		Carcinogenic	25,550

a Recommended average inhalation rate for outdoor workers (EPA 1989b).

b The ET is based on 4 hours of exposure at the site per day.

c Assumes exposure at the landfills 3 days per week, 50 weeks per year, and accounts for 60 days/yr of snowcover, 3/7 of which are assumed to occur during days when landfill workers are onsite.

d Assumes landfill closure within 5 years.

Table 5-4 Dermal Contact With Surface Soil, Current Onsite Worker

$$\text{Intake Factor} = \frac{SA \times AB \times AF \times FC \times EF \times ED \times CF}{BW \times AT}$$

Parameter			RME
SA	=	Surface area (cm^2)[a]	2,910
AB	=	Absorption factor[b]	chemical-specific
AF	=	Adherence factor (mg/cm^2)[c]	0.6
FC	=	Fraction contacted from contaminated source[d]	0.5
EF	=	Exposure frequency (days/year)[f]	124
ED	=	Exposure duration (years)[e]	5
CF	=	Conversion factor (kg/mg)	10^{-6}
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	1,825
		Carcinogenic	25,550

[a] The RME surface area is equivalent to face, forearms, and hands, or 15 percent of total body surface (EPA 1989b).

[b] Absorption of metals from a soil matrix is negligible (EPA 1991a). The absorption factor for semivolatiles, volatiles, and other organics is likely to be lower than 100% and will be determined on a chemical-specific basis.

[c] This is a median value from the range (average to upper estimate) for soil adherence values recommended by EPA (EPA 1992b).

[d] Based on 4 hours of exposure to soil per 8-hour workday.

[e] Assumes landfill closure within 5 years.

[f] Assumes exposure at the landfills 3 days per week, 50 weeks per year, and accounts for 60 days/yr of snowcover, 3/7 of which are assumed to occur during days when landfill workers are onsite.

Table 5-5 External Irradiation (Groundshine), Current Onsite Worker

$$\text{Exposure Factor} = \frac{ET \times EF \times ED}{ET_B \times EF_B}$$

		Parameter	RME
ET	=	Exposure time (hours/day)[a]	4
ET_B	=	Baseline exposure time (hours/day)[b]	24
ED	=	Exposure duration (years)[c]	5
EF	=	Exposure frequency (days/year)[d]	124
EF_B	=	Baseline exposure frequency (days/year)[e]	365

[a] The ET is based on 4 hours of exposure to site soils per 8-hour work day.
[b] Baseline exposure time from HEAST.
[c] Based on continued use of the present landfill for a maximum of 5 years.
[d] Based on the current landfill worker schedule of 3 days/week, 50 weeks per year, and accounts for 60 days/yr of snowcover, 3/7 of which are assumed to occur during days when landfill workers are on site.
[e] Baseline exposure frequency from HEAST.

Table 5-6 Soil Ingestion, Hypothetical Future Onsite Worker

$$\text{Intake Factor} = \frac{IR \times FI \times ME \times EF \times ED \times CF}{BW \times AT}$$

Parameter			RME
IR	=	Ingestion rate (mg/day)[a]	50
FI	=	Fraction ingested from contaminated source[b]	0.125
ME	=	Matrix effect[c]	chemical-specific
EF	=	Exposure frequency (days/year)[d]	207
ED	=	Exposure duration (years)[a]	25
CF	=	Conversion factor (kg/mg)	10^{-6}
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	9,125
		Carcinogenic	25,550

[a] EPA 1991b.

[b] Based on 1-hour of exposure to site soil per 8-hour workday.

[c] The matrix effect describes the reduced availability due to adsorption of chemicals to soil compared to the same dose administered in solution. Therefore, the soil matrix has the effect of reducing the dose of a compound (Poiger and Schlatter 1980). These values are chemical-specific.

[d] EPA 1991b, adjusted for snowcover. Assumes the standard 250 days/year occupational exposure frequency, but accounts for 60 days/year of snowcover; 5/7 of which are assumed to occur during the work week.

Table 5-7 Inhalation of Particulates, Hypothetical Future Onsite Worker

$$\text{Intake Factor} = \frac{IR \times ET \times EF \times ED \times DF}{BW \times AT}$$

		Parameter	RME
IR	=	Inhalation rate (m^3/hr)[a]	0.63
ET	=	Exposure time (hours/day)[b]	8
EF	=	Exposure frequency (days/year)[c,e]	207
ED	=	Exposure duration (years)[c]	25
DF	=	Deposition factor[d]	0.25
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	2,125
		Carcinogenic	25,550

[a] Recommended inhalation rate for indoor workers (EPA 1989b).

[b] The ET is based on an 8-hour workday.

[c] EPA 1991b.

[d] Twenty-five percent of inhaled particles are deposited and remain in the lung; it is assumed that all of the chemicals in that fraction are absorbed (MRI 1985).

[e] Assumes the standard 250 days/year occupational exposure frequency, but accounts for 60 days/year of snowcover, 5/7 of which are assumed to occur during the work week.

Table 5-8 Inhalation of VOCs, Hypothetical Future Onsite Worker

$$\text{Intake Factor} = \frac{IR \times ET \times EF \times ED \times AF}{BW \times AT}$$

		Parameter	RME
IR	=	Inhalation rate (m^3/hr)[a]	0.63
ET	=	Exposure time (hours/day)[b]	8
EF	=	Exposure frequency (days/year)[c,d]	207
ED	=	Exposure duration (years)[c]	25
AF	=	Absorption Fraction	chemical-specific
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	9,125
		Carcinogenic	25,550

[a] Recommended inhalation rate for indoor workers (EPA 1989b).

[b] The ET is based on an 8-hour workday.

[c] EPA 1991b.

[d] Assumes the standard 250 days/year occupational exposure frequency, but accounts for 60 days/year of snowcover, 5/7 of which are assumed to occur during the work week. (Owen 1990)

Table 5-9 Dermal Contact With Surface Soil, Hypothetical Future Onsite Worker

$$\text{Intake Factor} = \frac{SA \times AB \times AF \times FC \times EF \times ED \times CF}{BW \times AT}$$

		Parameter	RME
SA	=	Surface area (cm^2)[a]	2,910
AB	=	Absorption factor[b]	chemical-specific
AF	=	Adherence factor (mg/cm^2)[c]	0.6
FC	=	Fraction contacted from contaminated source[d]	0.125
EF	=	Exposure frequency (days/year)[e,f]	207
ED	=	Exposure duration (years)[e]	25
CF	=	Conversion factor (kg/mg)	10^{-6}
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	9,125
		Carcinogenic	25,550

[a] The RME surface area is equivalent to face, forearms, and hands, or 15 percent of total body surface (EPA 1989b).

[b] Absorption of metals from a soil matrix is negligible (EPA 1991a). The absorption factor for semivolatiles, volatiles, and other organics is likely to be lower than 100% and will be determined on a chemical-specific basis.

[c] This is a median value from the range (average to upper estimate) for soil adherence values recommended by EPA (EPA 1992b).

[d] Based on 1 hour of exposure to soil per 8-hour workday.

[e] EPA 1991b.

[f] Assumes the standard 250 days/year occupational exposure frequency, but accounts for 60 days/year of snowcover; 5/7 of which are assumed to occur during the work week.

Table 5-10 External Irradiation (Groundshine), Hypothetical Future Onsite Worker

$$\text{Exposure Factor} = \frac{ET \times EF \times ED}{ET_B \times EF_B}$$

		Parameter	RME
ET	=	Exposure time (hours/day)[a]	8
ET_B	=	Baseline exposure time (hours/day)[b]	24
ED	=	Exposure duration (year)[c]	25
EF	=	Exposure frequency (days/year)[d]	124
EF_B	=	Baseline exposure frequency (day/year)[e]	365

a The ET is based on an 8-hour work day.
b Baseline exposure time from HEAST.
c Human Health Evaluation Manual, Supplemental Guidance: "Standard Default exposure Factors" (EPA 1991b).
d Assumes the standard 250 days/year occupational exposure frequency, but accounts for 60 days/year of snowcover, 5/7 of which are assumed to occur during the work week.
e Baseline exposure frequency from HEAST.

Table 5-11 Soil Ingestion, Hypothetical Future Onsite Ecological Researcher

$$\text{Intake Factor} = \frac{IR \times FI \times ME \times EF \times ED \times CF}{BW \times AT}$$

		Parameter	RME
IR	=	Ingestion rate (mg/day)[a]	50
FI	=	Fraction ingested from contaminated source[b]	.006
ME	=	Matrix effect[c]	chemical-specific
EF	=	Exposure frequency (days/year)[d]	80
ED	=	Exposure duration (years)[e]	7
CF	=	Conversion factor (kg/mg)	10^{-6}
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	2,555
		Carcinogenic	25,550

a EPA 1991b.

b The FI assumes that, while at RFP, the ecological researchers spend time at OU7 as a relative proportion of the area of OU7 to total area of the buffer zone.

c The matrix effect describes the reduced availability due to adsorption of chemicals to soil compared to the same dose administered in solution. Therefore, the soil matrix has the effect of reducing the intake of a compound (Poiger and Schlatter 1980). These values are chemical-specific.

d Equivalent to 5 days/week for 16 weeks each year (field season).

e Based on guidance provided by IAG members.

Table 5-12 *Inhalation of Particulates,* Hypothetical Future Onsite Ecological Researcher

$$\text{Intake Factor} = \frac{IR \times ET \times FC \times EF \times ED \times DF}{BW \times AT}$$

		Parameter	RME
IR	=	Inhalation rate (m^3/hr)[a]	1.4
ET	=	Exposure time (hours/day)[b]	8
FC	=	Fraction from Contaminated Source[c]	.006
EF	=	Exposure frequency (days/year)[d]	80
ED	=	Exposure duration (years)[e]	7
DF	=	Deposition factor [f]	0.25
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	2,555
		Carcinogenic	25,550

a Recommended average value for outdoor workers (EPA 1989b).
b The ET assumes an 8-hour workday.
c The FC assumes that, while at RFP, the ecological researchers spend time at OU7 as a relative proportion of the area of OU7 to the area of the entire buffer zone.
d Equivalent to 5 days/week for 16 weeks (field season).
e Based on guidance provided by IAG members.
f Twenty-five percent of inhaled particles are deposited and remain in the lung; it is assumed that all chemicals in that fraction are absorbed (MRI 1985).

Table 5-13 Inhalation of VOCs, Hypothetical Future Onsite Ecological Researcher

$$\text{Intake Factor} = \frac{IR \times ET \times FC \times EF \times ED \times AF}{BW \times AT}$$

		Parameter	RME
IR	=	Inhalation rate (m^3/hr)[a]	1.4
ET	=	Exposure time (hours/day)[b]	8
FC	=	Fraction from Contaminated Source[c]	.006
EF	=	Exposure frequency (days/year)[d]	80
ED	=	Exposure duration (years)[e]	7
DF	=	Absorption Fraction	chemical-specific
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	2,555
		Carcinogenic	25,550

[a] Recommended average value for outdoor workers (EPA 1989b).
[b] The ET assumes an 8-hour workday.
[c] The FC assumes that while at RFP, the ecological researchers spend time at OU7 as a relative proportion of the area of OU7 to the area of the entire buffer zone.
[d] Equivalent to 5 days/week for 16 weeks (field season).
[e] Based on guidance provided by IAG members.

Table 5-14 Dermal Contact With Surface Soil, Hypothetical Future Onsite Ecological Researcher

$$\text{Intake Factor} = \frac{SA \times AB \times AF \times FC \times EF \times ED \times CF}{BW \times AT}$$

		Parameter	RME
SA	=	Surface area (cm^2)[a]	2,910
AB	=	Absorption factor[b]	chemical-specific
AF	=	Adherence factor (mg/cm^2)[c]	0.6
FC	=	Fraction contacted from contaminated source[d]	.006
EF	=	Exposure frequency (days/year)[e]	80
ED	=	Exposure duration (years)[f]	7
CF	=	Conversion factor (kg/mg)	10^{-6}
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	2,555
		Carcinogenic	25,550

[a] The RME surface area is equivalent to face, forearms, and hands, or 15 percent of total body surface (EPA 1989b).

[b] Absorption of metals from a soil matrix is negligible (EPA 1991a). The absorption factor for semivolatiles, volatiles, and other organics is likely to be lower than 100% and will be determined on a chemical-specific basis.

[c] This is a median value from the range (average to upper estimate) for soil adherence values recommended by EPA (EPA 1992b).

[d] The FC assumes that while at RFP, the ecological researchers spend time at OU7 as a relative proportion of the area of OU7 to the area of the entire buffer zone.

[e] Equivalent to 5 days/week for 16 weeks (field season).

[f] Based on guidance provided by IAG members.

Table 5-15 External Irradiation (Groundshine), Hypothetical Future Onsite Ecological Researcher

$$\text{Exposure Factor} = \frac{ET \times EF \times ED \times FE}{ET_B \times EF_B}$$

		Parameter	RME
ET	=	Exposure time (hours/day)[a]	8
ET_B	=	Baseline exposure time (hours/day)[b]	24
ED	=	Exposure duration (yr)[c]	7
EF	=	Exposure frequency (days/yr)[d]	80
EF_B	=	Baseline exposure frequency (day/yr)[e]	365
FE	=	Fraction exposed from contaminated surface[f]	.006

a The ET assumes an 8-hour work day.
b Baseline exposure time from HEAST.
c Based on guidance provided by IAG members.
d Equivalent to 5 days/week for 16 weeks (field season).
e Baseline exposure frequency from HEAST.
f The FE assumes that while at RFP, the ecological researchers spend time at OU7 as a relative proportion of the area of OU7 to the area of the entire buffer zone.

Table 5-16 Soil Ingestion, Hypothetical Future Onsite Resident (Adult and Child)[a]

$$\text{Intake Factor} = \frac{IR \times FI \times ME \times EF \times ED \times CF}{BW \times AT}$$

Parameter			RME	
			Adult	Child
IR	=	Ingestion rate (mg/day)[b]	100	200
FI	=	Fraction ingested from contaminated source[c]	0.5	0.5
ME	=	Matrix effect[d]	chemical-specific	
EF	=	Exposure frequency (days/year)[b,e]	290	290
ED	=	Exposure duration (years)[b]	24	6
CF	=	Conversion factor (kg/mg)	10^{-6}	10^{-6}
BW	=	Body weight (kg)	70	15
AT	=	Averaging time (days)		
		Noncarcinogenic	8,760	2,190
		Carcinogenic	23,360	2,190

[a] The calculation of a 30-year residential exposure to soil is divided into two parts. First, a six-year exposure duration is evaluated for young children, and this accounts for the period of highest soil ingestion (200 mg/day) and lowest body weight (15 kg). Second, a 24-year exposure duration is assessed for older children and adults by using a lower soil ingestion rate (100 mg/day) and an adult body weight (70 kg). These two periods are then time-averaged (EPA 1991b).

[b] EPA-recommended value (1991b).

[c] The RME (FI) assumes that residents are in contact with contaminated soils 50 percent of their time at home.

[d] The matrix effect describes the reduced availability due to adsorption of chemicals to soil compared to the same dose administered in solution. Therefore, the soil matrix has the effect of reducing the intake of the compound. These values are chemical-specific.

[e] Adjusted for snowcover of 60 days per year.

Table 5-17 Ingestion of Homegrown Vegetables, Hypothetical Future Onsite Resident

$$\text{Intake Factor} = \frac{IR \times FI \times ME \times EF \times ED \times CF}{BW \times AT}$$

Parameter		RME
IR:	Ingestion rate, vegetables (mg/day)[a]	200,000
FI:	Fraction ingested from contaminated source[b]	0.4
ME:	Matrix effect	chemical-specific
EF:	Exposure frequency (days/year)[c]	122
ED:	Exposure duration (years)	30
CF:	Conversion factor (kg/mg)	10^{-6}
BW:	Body weight (kg)	70
AT:	Averaging time (days)	
	Noncarcinogenic	10,950
	Carcinogenic	25,550

a This ingestion rate is based on the typical consumption value of vegetables.

b "Reasonable worst case" proportion that is homegrown of 40% (EPA 1991b).

c Homegrown vegetable consumption assumed to occur every day during the four month harvest period (June-September).

Table 5-18 Inhalation of Particulates, Hypothetical Future Onsite Resident

$$\text{Intake Factor} = \frac{IR \times ET \times EF \times ED \times DF}{BW \times AT}$$

		Parameter	RME
IR	=	Inhalation rate (m^3/hr)[a]	0.83
ET	=	Exposure time (hours/day)[b]	24
EF	=	Exposure frequency (days/year)[c,e]	290
ED	=	Exposure duration (years)[c]	30
DF	=	Deposition factor[d]	0.25
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	10,950
		Carcinogenic	25,550

[a] This is equivalent to 20 m^3/day (EPA 1991b).
[b] This RME exposure time assumes that 24 hours per day is spent at home.
[c] EPA 1991b.
[d] Twenty-five percent of inhaled particles are deposited and remain in the lung; it is assumed that all chemicals in that fraction are absorbed (MRI 1985).
[e] Adjusted for snowcover of 60 days per year.

Table 5-19 Inhalation Of VOCs, Hypothetical Future Onsite Resident

$$\text{Intake Factor} = \frac{IR \times ET \times EF \times ED \times AF}{BW \times AT}$$

Parameter			RME
IR	=	Inhalation rate (m^3/hr)[a]	0.83
ET	=	Exposure time (hours/day)[b]	24
EF	=	Exposure frequency (days/year)[c,d]	290
ED	=	Exposure duration (years)[c]	30
AF	=	Absorption Fraction	chemical-specific
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	9,125
		Carcinogenic	25,550

a This is equivalent to 20 m^3/day (EPA 1991b).
b This RME exposure time assumes that 24 hours per day are spent at home.
c EPA 1991b.
d Adjusted for snowcover of 60 days per year.

Table 5-20 Dermal Contact With Surface Soil, Hypothetical Future Onsite Resident

$$\text{Intake Factor} = \frac{SA \times AB \times AF \times FC \times EF \times ED \times CF}{BW \times AT}$$

		Parameter	RME
SA	=	Surface area (cm^2)[a]	2,910
AB	=	Absorption factor[b]	chemical-specific
AF	=	Adherence factor (mg/cm^2)[c]	0.6
FC	=	Fraction contacted from contaminated source[d]	0.5
EF	=	Exposure frequency (days/year)[e]	290
ED	=	Exposure duration (years)[e]	30
CF	=	Conversion factor (kg/mg)	10^{-6}
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	10,950
		Carcinogenic	25,550

[a] The RME surface area is equivalent to face, forearms, and hands, or 15 percent of total body surface (EPA 1989b).

[b] Absorption of metals from a soil matrix is negligible (EPA 1991a). The absorption factor for semivolatiles, volatiles, and other organics is likely to be lower and will be determined on a chemical-specific basis.

[c] EPA 1992b.

[d] The FC assumes that residents are in contact with chemical-containing media 50 percent of their time at home.

[e] EPA 1991b, adjusted for snowcover of 60 days/year.

Table 5-21 External Irradiation (Groundshine), Hypothetical Future Onsite Resident

$$\text{Exposure Factor} = \frac{ET \times EF \times ED}{ET_B \times EF_B}$$

		Parameter	SAICRME
ET	=	Exposure time (hours/day)[a]	24
ET_B	=	Baseline exposure time (hours/day)[b]	24
ED	=	Exposure duration (yr)[c]	30
EF	=	Exposure frequency (days/yr)[c]	350
EF_B	=	Baseline exposure frequency (day/yr)[d]	365

[a] The RME exposure time assumes 24 hours per day are spent at home.
[b] Baseline exposure time from HEAST.
[c] Human Health Evaluation Manual, Supplemental Guidance: "Standard Default Exposure Factors" (EPA 1991b).
[d] Baseline exposure frequency from HEAST.

6.0 REFERENCES

AEC (Atomic Energy Commission). 1972. Environmental Statement. *Land Acquisition, Rocky Flats Plant, Colorado*. April.

ASI (Applied Sciences, Inc.). 1991. Threatened and endangered species evaluation -- Rocky Flats Plant Site. Prepared for EG&G Rocky Flats, Inc. April 4.

Baker, B. 1988. Personal communications. May 31 and June 1.

Boulder Daily Camera. 1992. "It's time to stop bashing Rocky Flats,' Watkins Says." Page 1A. June 13.

Boulder County. 1991. Zoning Map. Reception No. 1088470, Book No. P-25F-3. February.

City of Broomfield. 1990. Zoning Map. Rev. 5.0. December 20.

Clark, S.V., P.J. Webber, V. Komarkova, and W.A. Weber. 1980. *Map of Mixed Prairie Grassland Vegetation, Rocky Flats, Colorado.* Occasional Paper No. 35. Boulder, Colorado: Institute of Arctic and Alpine Research, University of Colorado.

Denver Post. 1992. "Watkins: Plant's Future Looks Bright." Page 1B. June 13.

DOE. 1980. *Final Environmental Impact Statement: Rocky Flats Plant Site, Golden, Jefferson County, Colorado*. Volumes 1, 2, and 3. Washington: U.S. Department of Energy. DOE/EIS-0064.

DOE. 1990. *1989 Population, Economic, and Land Use Data for Rocky Flats Plant*. Golden, Colorado: U.S. Department of Energy. August.

DOE. 1991a. *Federal facility Agreement and Consent Order (Inter-Agency Agreement [IAG])*. January 22.

DOE. 1991b. *Final Phase I RFI/RI Work Plan, Rocky Flats Plant, Present Landfill IHSS 114 and Inactive Hazardous Waste Storage Area IHSS 203 (Operable Unit No. 7).* Golden, Colorado: U.S. Department of Energy. December.

DOE. 1992. *Public Health Risk Assessment, 881 Hillside Area (OU-1), Technical Memorandum No. 6, Exposure Scenarios.* Rev. 3.0. Rocky Flats Plant, Golden, Colorado. January.

Doesken, Nolan. 1992. Personal Communication. Assistant State Climatologist for Colorado. Fort Collins, Colorado. 30-year average annual days of snow cover for Lakewood, Colorado.

EG&G. 1990a. *1989 Annual RCRA Ground-Water Monitoring Report for Regulated Units at Rocky Flats Plant.* Golden, Colorado: EG&G Rocky Flats, Inc. March 1.

EG&G. 1990b. *Wetlands Assessment for U.S. DOE - Rocky Flats Plant.* Golden, Colorado: EG&G Rocky Flats, Inc. 32 pp. and map.

EG&G. 1990c. *Rocky Flats Plant Environmental Restoration Health and Safety Program Plan.* October 26.

EG&G. 1991a. *Phase II Geologic Characterization, Task 6 Surface Geologic Mapping Draft Report.* Golden, Colorado: EG&G Rocky Flats, Inc.

EG&G. 1991b. *Final Phase II RFI/RI Work Plan (Alluvial) 903 Pad, Mound, and East Trenches Areas (Operable Unit No. 2).* Golden, Colorado: EG&G Rocky Flats, Inc. August 19.

EG&G. 1991c. *1990 Annual RCRA Groundwater Monitoring Report for Regulated Units at Rocky Flats Plant.* Golden, Colorado: EG&G Rocky Flats, Inc. March.

EG&G. 1991d. *(Draft) 1989 Surface Water and Sediment Geochemical Characterization Report, Rocky Flats Plant*. Golden, Colorado: EG&G Rocky Flats, Inc.

EG&G. 1992a. *Phase II Geologic Characterization Data Acquisition - Surface Geologic Mapping of the Rocky Flats Plant and Vicinity, Jefferson and Boulder Counties, Final Report*. Golden, Colorado: EG&G Rocky Flats, Inc. March.

EG&G. 1992b. Personal communication between EG&G and Woodward-Clyde Risk Assessment Group. June 19.

EG&G. 1992c. *Health and Safety Practices*. Golden, Colorado: EG&G Rocky Flats, Inc.

EPA. 1989a. *Risk Assessment Guidance for Superfund, Volume 1: Human Health Evaluation Manual*. Washington: U.S. Environmental Protection Agency, Office of Emergency and Remedial Response. EPA/540/1-89/002.

EPA. 1989b. *Exposure Factors Handbook*. Washington: U.S. Environmental Protection Agency, Office of Health and Environmental Assessment. EPA/600/8-89/043. July.

EPA. 1990. *Guidance for Data Useability in Risk Assessment*. Interim Final. Washington: U.S. Environmental Protection Agency, Office of Emergency and Remedial Response. EPA/540/G-90/008. October.

EPA. 1991a. Preliminary Human Health Baseline Risk Assessment for the California Gulch NPL Site, Leadville, Colorado. U.S. Environmental Protection Agency. Doc. Ctl. No. 4800-01-0722. December.

EPA. 1991b. Human Health Evaluation Manual, Supplemental Guidance: "Standard Default Exposure Factors." U.S. Environmental Protection Agency. OSWER Directive 9285.6-03.

EPA. 1992a. *Guidance on Risk Characterization for Risk Managers and Risk Assessors*. Memorandum from F. Henry Habicht II to Assistant and Regional Administrators.

Washington: U.S. Environmental Protection Agency, Office of the Administration. February 26.

EPA. 1992b. *Dermal Exposure Assessment: Principles and Applications*. Interim Report. Washington: U.S. Environmental Protection Agency, Office of Health and Environmental Assessment, Exposure Assessment Group. EPA/600/8-91/011B. January.

EPA. 1992c. *Health Effects Assessment Summary Tables. Annual 1992.* U.S. Environmental Protection Agency, Office of Research and Development and Office of Emergency and Remedial Response. March.

FWS. 1979. *Classification of Wetlands and Seepwater Habitats of the United States*. U.S. Fish and Wildlife Service, FWS/OBS-79/31.

Hodgin, C.R.; Ciolek, J.T.; Johnson, S.A.; and Stratton, M.A. 1990. *Wind Speed Analysis for Super Compactor Study*. Golden, Colorado: EG&G Rocky Flats, Inc.

Hunt, C.D. 1967. *Physiography of the United States.* San Francisco: W.H. Freeman and Company.

Hurr, R. T. 1976. *Hydrology of a Nuclear-Processing Plant Site, Rocky Flats, Jefferson County, Colorado*. U.S. Geological Survey Open-File Report 76-268.

Jefferson County. 1989. *Northeast Jefferson County, Community Profile Report*. Planning Department. August.

Jefferson County. 1990. *The North Plains Community Plan*. Planning Department. April.

Knight, Richard. 1992. Letter from Dr. Knight, CSU Fishery and Wildlife Biology Department, to EG&G Rocky Flats, Inc. received May 16.

Marr, J.W. 1964. The vegetation of the Boulder area. University of Colorado Museum, Leaflet 13:34-42. Boulder.

MRI (Midwest Research Institute). 1985. *Rapid Assessment of Exposure to Particulate Emissions for Surface Contamination Sites.* EPA/600/8-85/002. February.

NOAA. 1991. *Climatological Data Annual Summary: Colorado (Vol. 96, No. 13).* National Oceanic and Atmospheric Administration, ISSN 0145-0506. Asheville, North Carolina.

Poiger, H. and C. Schlatter. 1980. Influence of Solvents and Absorbents on Dermal and Intestinal Absorption of TCDD. Food, Cosmetology, and Toxicology. 18:477-481.

Rockwell International. 1988a. *Present Landfill Closure Plan, U.S. Department of Energy Rocky Flats Plant, Golden, Colorado.* Golden, Colorado: Rockwell International, Rocky Flats Plant.

Rockwell International. 1988b. *Closure Plan, Inactive Interim Status Facilities, Hazardous Waste Storage Area SWMU #203, Rocky Flats Plant, Golden, Colorado.* Golden, Colorado: Rockwell International, Rocky Flats Plant.

Rockwell International. 1988c. *Present Landfill Hydrogeologic Characterization Report, Rocky Flats Plant* (Appendix 6: Rockwell International 1988b). Golden, Colorado: Rockwell International, Rocky Flats Plant. July 1.

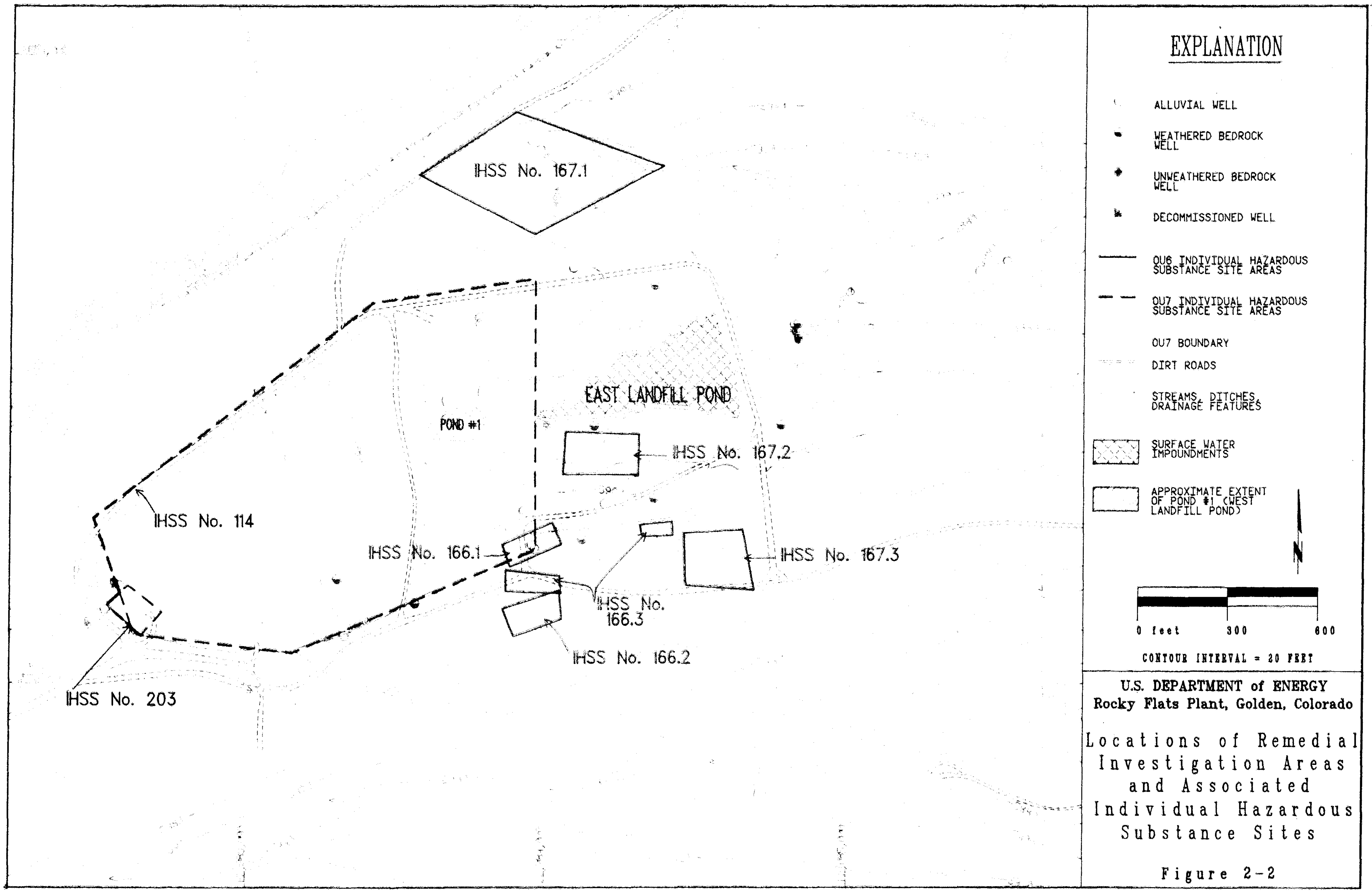
Rockwell International. 1989. *1988 Annual RCRA Groundwater Monitoring Report for Regulated Units at Rocky Flats Plant, Golden, Colorado.* Golden, Colorado: Rockwell International, Rocky Flats Plant. March 1.

Rocky Flats Local Impacts Initiative (RFLII). 1992. Statement of Purpose. Broomfield, Colorado. July 30.

Thornbury, W.D. 1965. *Regional Geomorphology of the United States.* New York: John Wiley & Sons, Inc.

Whicker, F.W., T.B. Kirchner, D.D. Breshears, and M.D. Otis. 1990. Estimation of radionuclide ingestion: The "Pathway" Food-Chain Model. Health Physics. Vol. 59, No. 5. pp. 645-657.

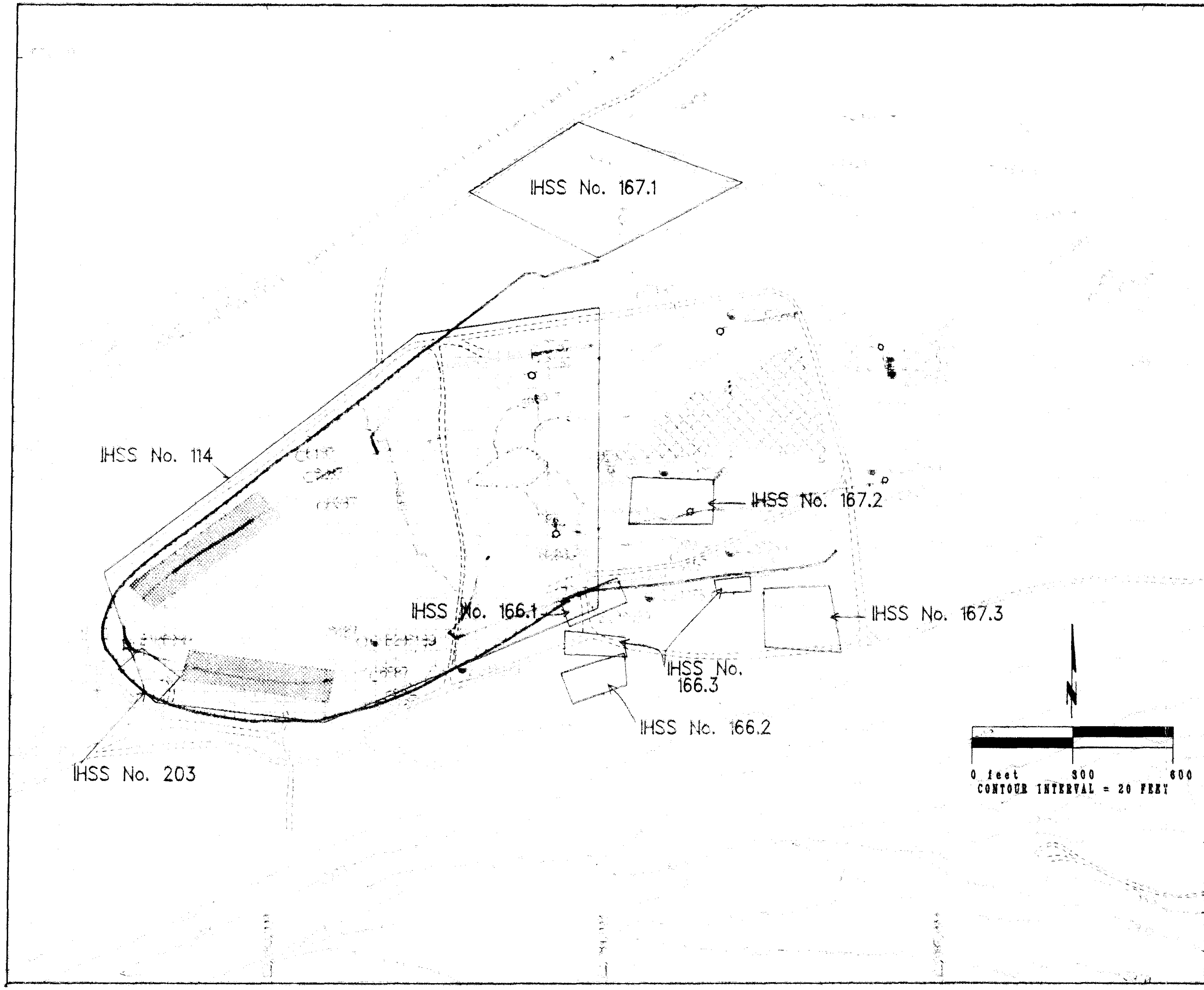
Woodward-Clevenger & Associates, Inc. 1974. *Geotechnical Services, Proposed and Existing Landfills, Dow Chemical, Rocky Flats Plant, Near Golden, Colorado*. Job No. 17536-350. January 17.



U.S. DEPARTMENT of ENERGY
Rocky Flats Plant, Golden, Colorado

Locations of Remedial Investigation Areas and Associated Individual Hazardous Substance Sites

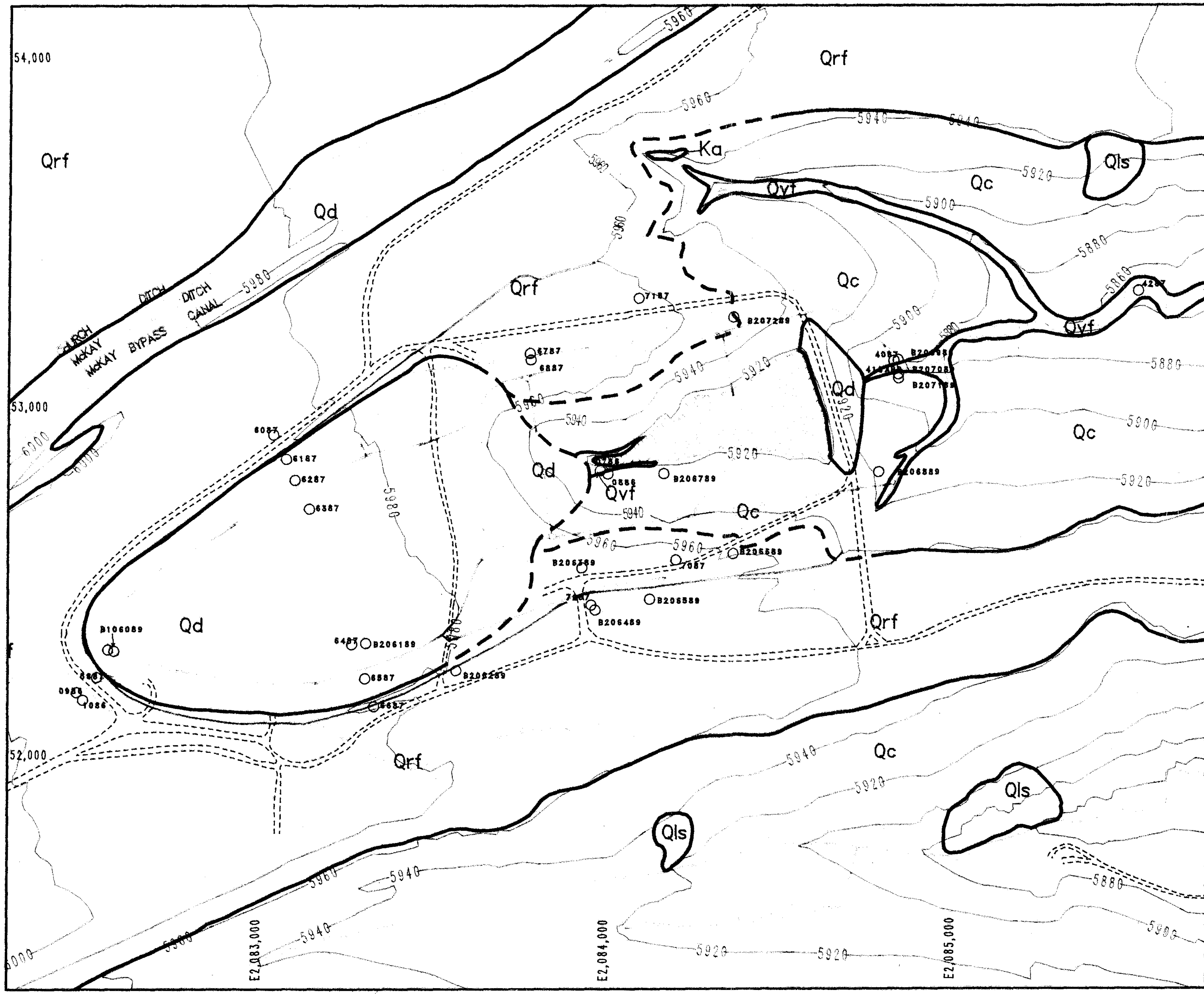
Figure 2-2



U.S. DEPARTMENT of ENERGY
Rocky Flats Plant, Golden, Colorado

Landfill Structures

Figure 2-3



EXPLANATION

Quarternary

Qd	Disturbed Ground
Qls	Quarternary Landslide
Qc	Colluvium
Qvf	Valley Fill Alluvium
Qrf	Rocky Flats Alluvium

Cretaceous

Ka	Arapahoe Formation (Claystone)
	Landfill Structures
	Geologic Contact, Dashed Where Inferred
B206489	Ground Water Monitoring Wells

0 feet 300 600

Contour Interval = 20 Feet

U.S. DEPARTMENT of ENERGY

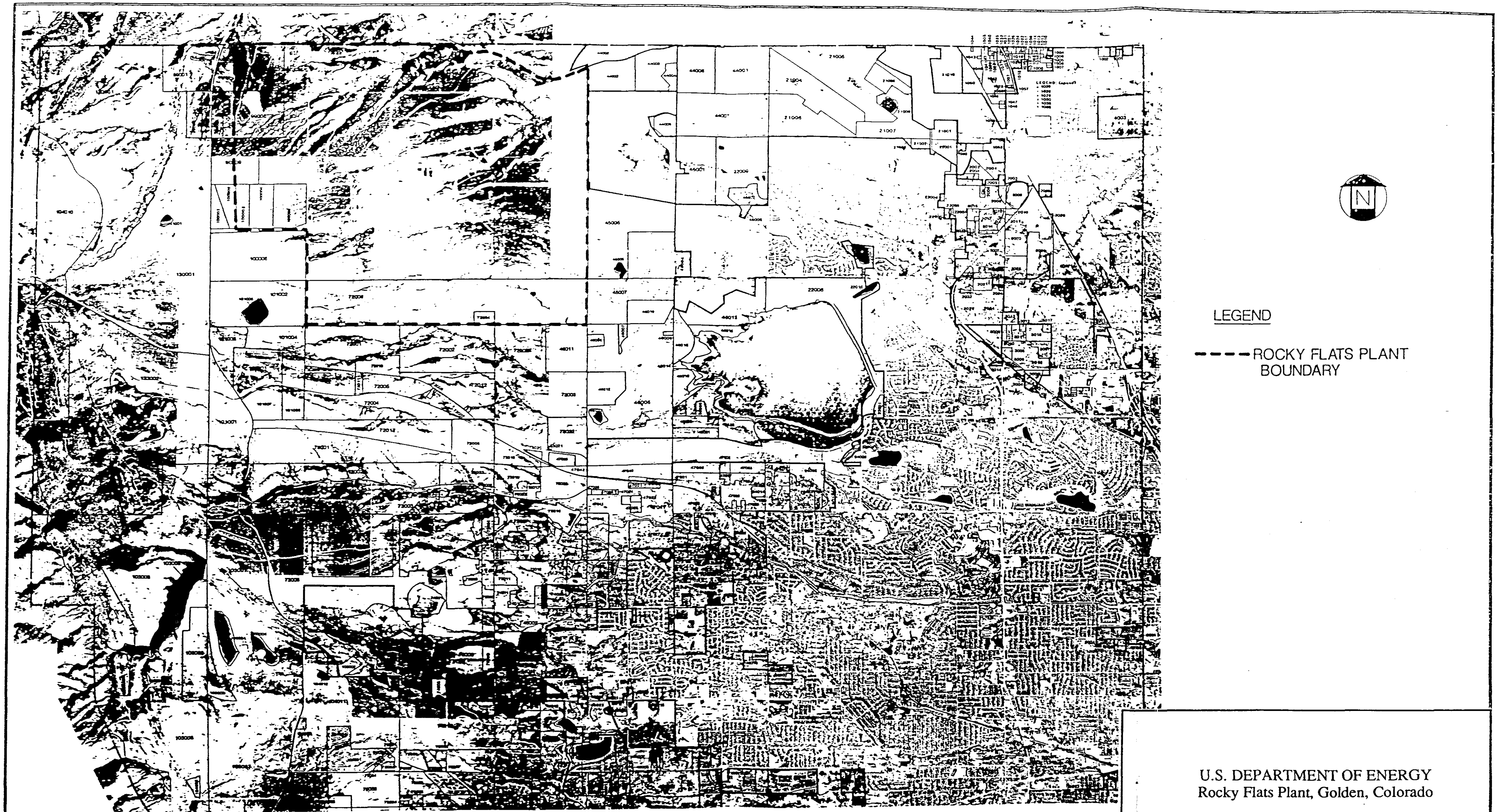
Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT 7

SURFICIAL GEOLOGY MAP

Note: Modified from Rockwell International 1988 using EG&G 1991 (Phase II Geologic Characterization Draft Report)

Figure 2-6



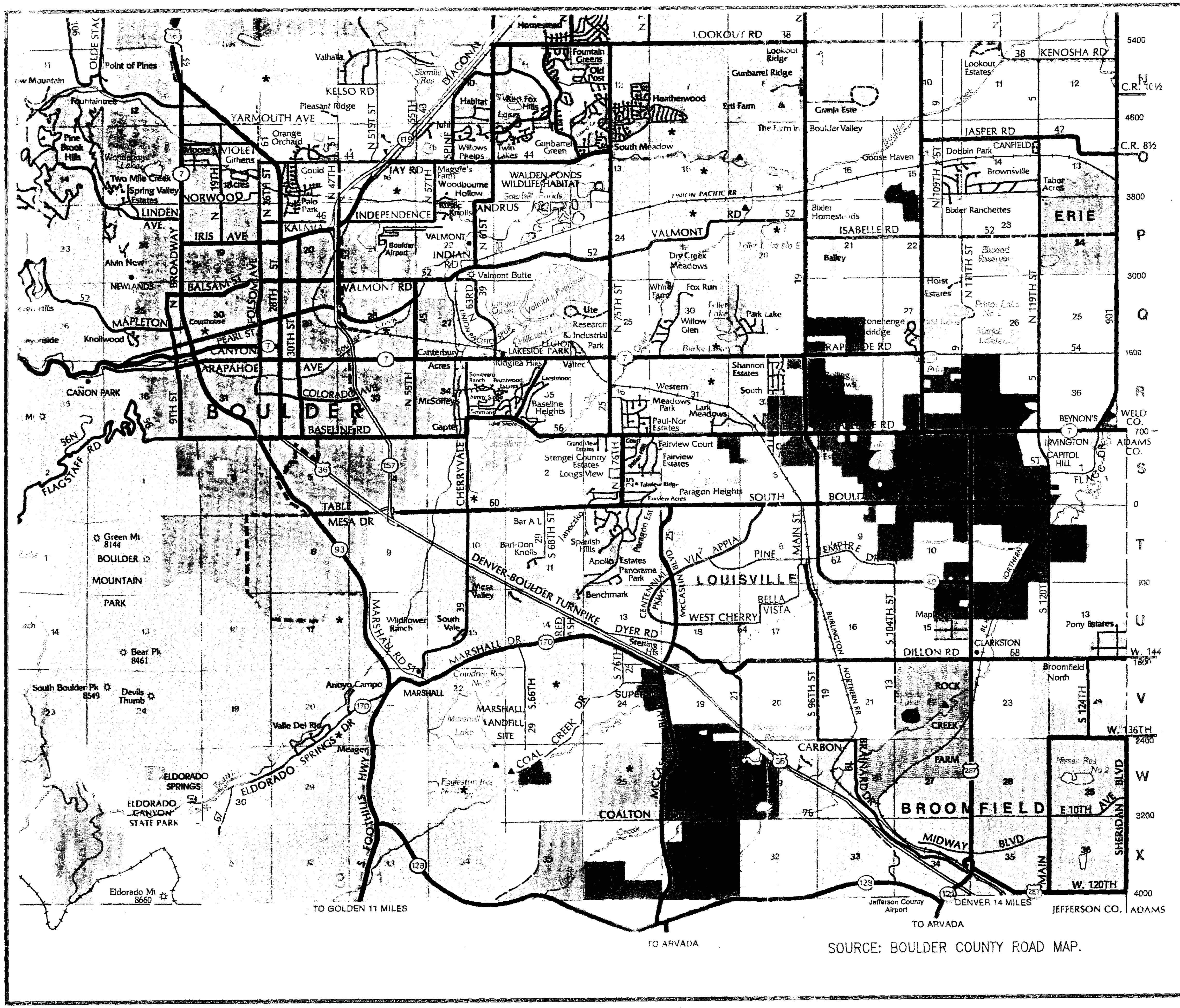
SOURCE: JEFFERSON COUNTY LAND USE INVENTORY MAP.

U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

Current Land Use
in Jefferson County

Figure 3-3

23047033

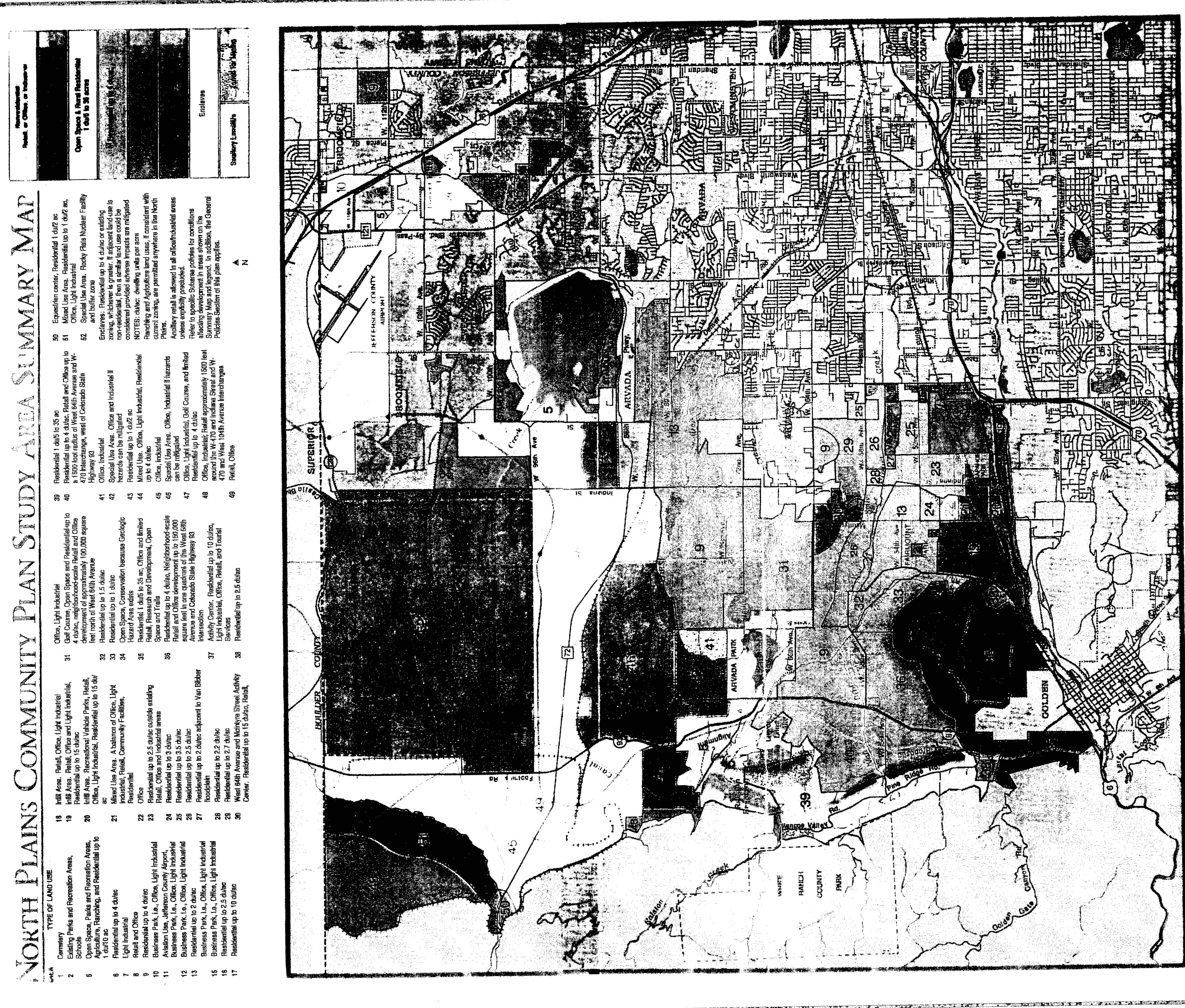


U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

Current Land Use
in Boulder County

Figure 3-4

23047034

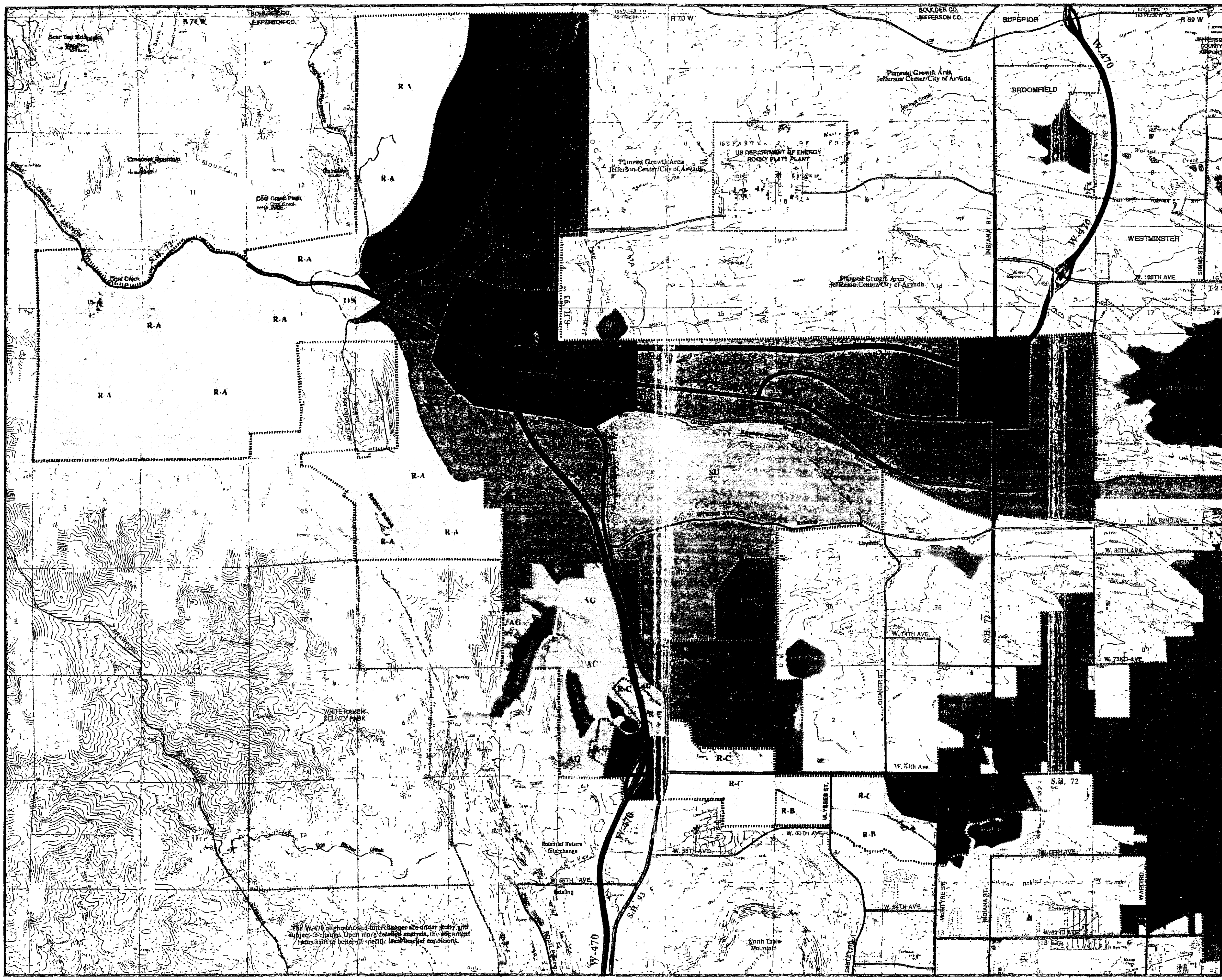


U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

Future Land Use
in Jefferson County

Figure 3-5

23047035



JEFFERSON COUNTY

City of Arvada

JCMD NO. 1

Jefferson Center Metropolitan District No. 1

Jefferson CENTER Associates

Jefferson Center Comprehensive Development Plan

FIGURE 3-6

Legend

- Commercial and Office
- Industrial and Office
- Mixed-Use: A B or C
- R Residential (A, B or C)
- AG Agricultural
- OS Open Space
- SU Special Use
- W- 470
- Arterial Roadways
- Collector Roadways
- Existing Roadways
- Jefferson Center Development Area

SOURCE: DOE 1992.

Approval

Jefferson County

By: Marjorie E. Clement Date: 8/15/89

Title: Chairman of the Board of the County Commissioners

ATTEST:

By: [signature] Deputy Date: 8-15-89

Title: County Clerk and Recorder

City of Arvada

By: George A. Ledorak Date: 8-14-89

Title: Mayor

ATTEST:

By: [signature] Date: 8-14-89

Title: City Clerk

Jefferson Center Metropolitan District No. 1

By: Howard W. Lacy Date: 11/7/89

Title: President

ATTEST:

By: [signature] Date: 11-9-89

Title: Secretary

Jefferson Center Associates

By: Howard W. Lacy Date: 8/14/89

Title: President

ATTEST:

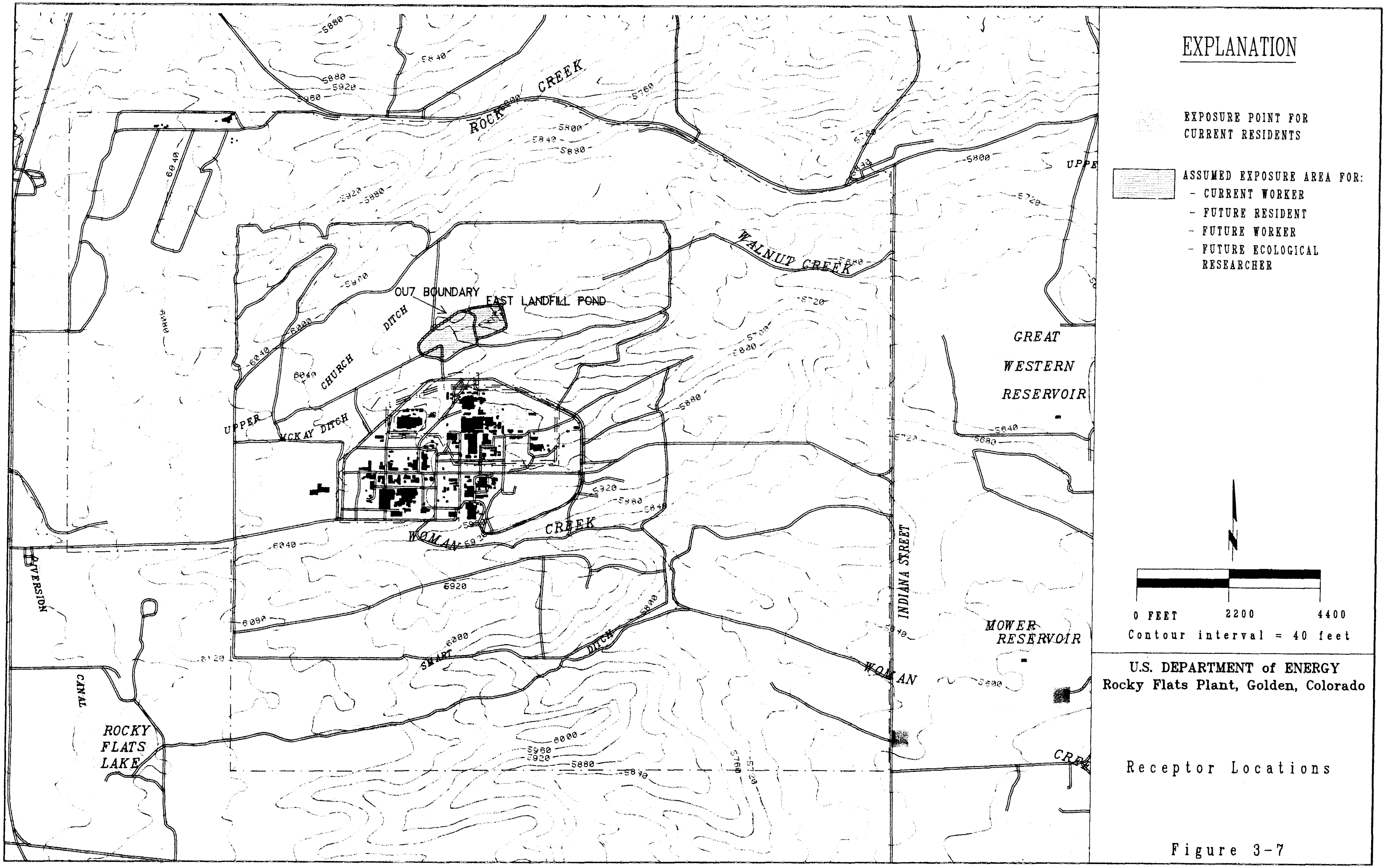
By: Bruce Nelson Date: 8/14/89

Title: Vice President

NORTH

Scale: 1" = 3000'

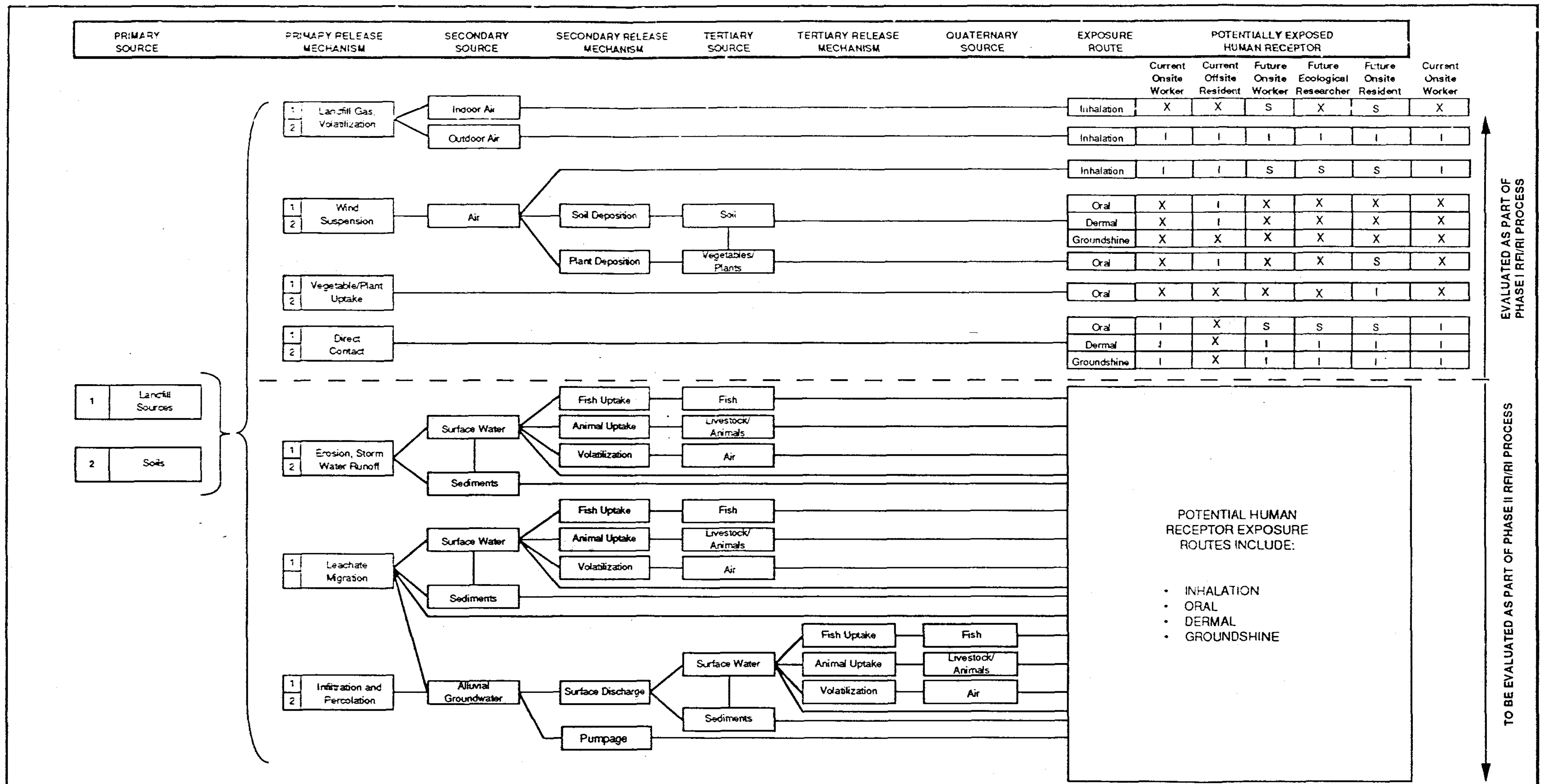
August 1,



U.S. DEPARTMENT of ENERGY
Rocky Flats Plant, Golden, Colorado

Receptor Locations

Figure 3-7



Exposure Route	Current Onsite Worker	Current Offsite Resident	Future Onsite Worker	Future Ecological Researcher	Future Onsite Resident	Current Onsite Worker
Inhalation	X	X	S	X	S	X
Inhalation	I	I	I	I	I	I
Inhalation	I	I	S	S	S	I
Oral	X	I	X	X	X	X
Dermal	X	I	X	X	X	X
Groundshine	X	X	X	X	X	X
Oral	X	I	X	X	S	X
Oral	X	X	X	X	I	X
Oral	I	X	S	S	S	I
Dermal	I	X	I	I	I	I
Groundshine	I	X	I	I	I	I

Legend

S Significant Potential Exposure Pathway (Conceivable and Relatively More Important)
I Insignificant Potential Exposure Pathway (Conceivable, Though Not As Important)
X Negligible and/or Incomplete Exposure Pathway (Unlikely to Occur)

U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado
OPERABLE UNIT 7
PHASE I RFI/RI EXPOSURE ASSESSMENT

Figure 4-1 Conceptual Site Model

M65WWM/EXPOSURE PATHWAYS.MOW 1/14/93